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THE EFFECTS OF AEROBIC AND ANAEROBIC TREATMENTS ON THE DECOMPOSITION OF BEEF CATTLE WASTES

by

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled "The Effects of Aerobic and Anaerobic Treatments on the Decomposition of Beef Cattle Wastes" submitted by Arne Knut Aasen in partial fulfilment of the requirements for the degree of Master of Science.

ABSTRACT

The principle objective of this project was to investigate the effects of aerobic and anaerobic treatments on the decomposition of beef cattle wastes under practical conditions. The wastes of confined feeder beef cattle on a slatted floor were collected and stored in pits over a period of thirty weeks. To provide aerobic conditions in the liquid waste, the oxidation ditch method was used in two of the pits. One of the pits was equipped with one rotor and the second with two rotors to provide slurry aeration. The two anaerobic pits received no aeration. Over the last nineteen weeks of the test period, weekly samples were obtained from each pit. The analyses of the waste samples included tests for biochemical oxygen demand, oxygen demand index, total and volatile total solids, pH, moisture content, specific gravity, total nitrogen content in the liquid and in the dry matter, and phosphorous and potassium content.

From the analysis of the data, the following results and conclusions were obtained:

1. Significant concentration differences between forms of decomposition were found for all variables except total nitrogen. Removing the effect of dilution, the only significant differences were for five-day biochemical oxygen demand, total and ammonia nitrogen, and phosphorous.
2. The pollution potential, based on five-day biochemical oxygen demand, of the aerobic pits was greatly reduced compared to the anaerobic pits.

3. Between the two levels of aeration, significant concentration differences were found for total and volatile total solids, organic nitrogen, and potassium. No significant differences were shown after removing the effect of dilution.
4. Multiple regression analysis showed that prediction equations for five-day biochemical oxygen demand, using total solids and oxygen demand index as independent variables, were possible.
5. Using multiple regression analysis, equations were developed to estimate the plant nutrient content of liquid beef cattle wastes.

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LIST OF SYMBOLS

BOD	biochemical oxygen demand
BOD_5	standard five-day, $20^{\circ}C$ BOD
BOD_{5T}	five-day BOD test data (average temperature = $24^{\circ}C$)
COD	chemical oxygen demand
db	dry basis (by weight)
DM	dry matter
k	first-stage BOD rate constant uncorrected for temperature
k_{20}	first-stage BOD rate constant corrected to $20^{\circ}C$
K	potassium
K_2O	potassium as potash
L	ultimate BOD of first-stage BOD
lb	pound(s)
mg	milligram(s)
mg/l	milligrams per liter
mg/g	milligrams per gram
ml	milliliter(s)
N	nitrogen
N_{NH_3}	ammonia nitrogen
N_O	organic nitrogen
N_T	total nitrogen
NO_3	nitrate nitrogen
ODI	oxygen demand index
P	phosphorous
P_2O_5	phosphorous as phosphoric acid
PE	population equivalent
pH	measurement of hydrogen ion concentration

SFTL	Soil and Feed Testing Laboratory
TS	total solids
VTS	volatile total solids
wb	wet basis (by weight)
^{o}C	degrees Centigrade
^{o}F	degrees Fahrenheit
%	percent or percentage

1. INTRODUCTION

The present concern of pollution from agricultural operations is relatively new. The lack of knowledge concerning the massive and virtually unknown pollution potential from agricultural production demands immediate attention.

As recently as two to three decades ago, farms were not serious sources of pollution largely due to the conventional methods of food production and the natural separation between rural and urban areas. Mechanization, technology and the demand for inexpensive farm products has removed these safeguards through the specialization of grain and livestock production.

This specialization in livestock production has resulted in concentrated production of manure. This concentration, along with the increased use of the more easily handled commercial fertilizers in forage and grain production, has resulted in problems of disposal of the manure both in its solid and liquid forms. Urban sprawl into the rural areas has increased public awareness to the environmental problems of agricultural production. It is these changes that have brought about the concern for animal waste management.

Environmental pollution is the undesireable alteration of the surroundings, through man's activities, which affect the quality of soil, air and water resources. Webster's dictionary states that "to pollute" is "to make physically impure or unclean" (81). Therefore, the addition of any substance, even in minute quantities, renders another pure substance impure. The question arises as to what level of impurity may be tolerated. Some impurity or pollution is inevitable, but the level must be maintained within well defined guidelines. These guidelines have not been determined

in many cases while some that have been are subsequently found to be deficient in one or more respects. One reason that guidelines have not or can not be fairly determined is due to the lack of knowledge about the substance in question.

Research is fundamental to increase knowledge including knowledge of a substance such as animal wastes. Without knowledge of the various biological, physical and chemical properties and behaviors of these wastes, the development and application of the engineering aspects of their management and disposal has been severely handicapped. During the last five to ten years, some insight has been acquired of the nature and behavior of animal wastes during storage, treatment and disposal. However, the majority of this information is related to wastes from poultry and swine. Initially, the development of large scale confinement systems was largely associated with hog and poultry production and consequently the waste problem became apparent sooner in such units.

By comparison, data concerned with the nature and behavior of cattle wastes is relatively sparse. The trend towards increased use of confinement systems in beef and dairy production has been accelerating rapidly in recent years. The resultant waste by-products from such operations are equally as serious a problem as those found in pig and poultry units but the nature of the wastes, since they are derived from ruminants, may be expected to be different in many respects. Factual information on cattle wastes is a prerequisite to the design of effective treatment and disposal systems.

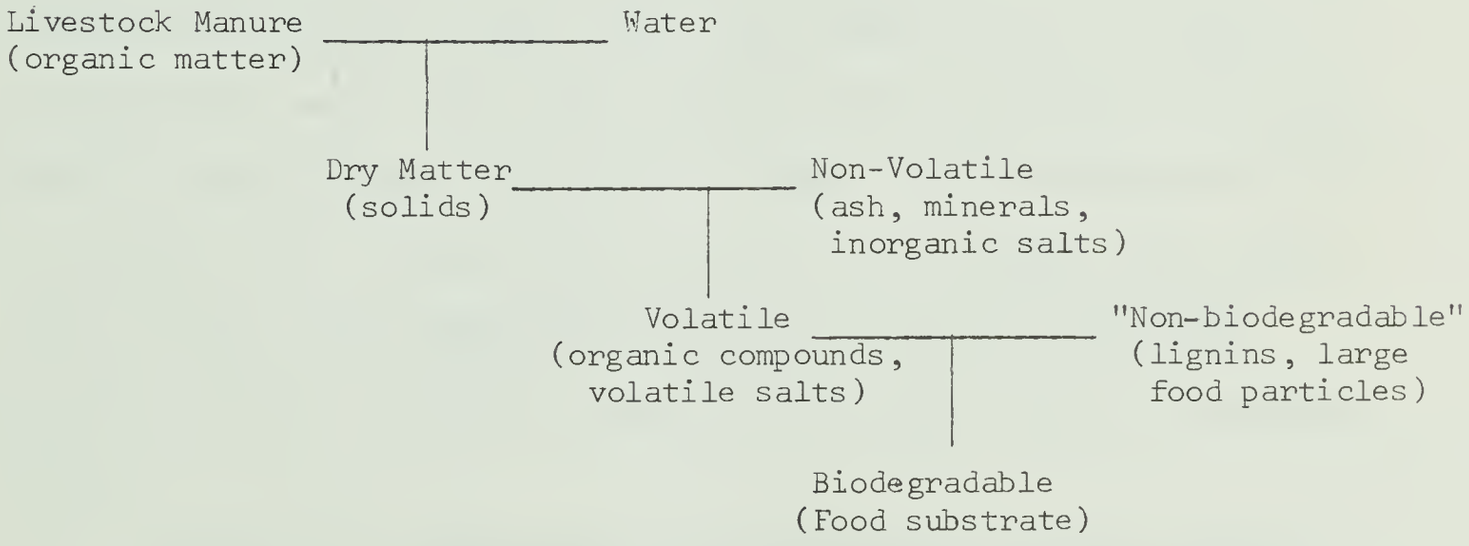
Therefore, the main purpose of this investigation was to study the effect of aerobic and anaerobic storage and decomposition on the manure wastes of beef cattle under fully enclosed confinement.

2. REVIEW OF LITERATURE

2.1 Livestock Wastes and Their Management

Manures and other livestock wastes are by-products of the livestock production industry. Increased technology and economic pressures have brought about the trend to larger units of production. Today, the production of eggs, broilers, turkeys and hogs is primarily undertaken in totally confined systems. Partial or complete confinement systems are used in milk production operations. In the beef industry, the swing to confined production is seen in the use of large feedlots and the newer totally enclosed confinement systems (35,40).

Livestock manures are largely a combination of water and organic matter. The following diagram shows some of the components of livestock manure that are important in livestock waste management (14).



2.1.1 Waste Production and Properties

The quantity and composition of livestock wastes depend largely on the animal species, animal age and weight, ration fed and the animal's environment (45,51). The use of antibiotics and copper compounds in feeds may influence the biological properties of the wastes by inhibiting or limiting the bacterial action (51).

From a review of eleven sources of data, Muehling (51) concluded that a 100 pound hog produces an average of 7.7 pounds per day of wastes with a range of 2.8 to 10.0 pounds. Using a density of 59 pounds per cubic foot (84), the volume produced is 0.13 cubic foot per hog per day. The Canadian Farm Building Standards (3) gives a value of 0.18 cubic foot for a similar size animal. Muehling(51) also states that the generally accepted range for waste production is 5 - 8 percent of the animal's liveweight of which 10 - 15 percent is total solids. His review found a value of 13.9 percent for total solids. Muehling (51) also found the following ranges: (1) 0.56 to 1.66 pounds per day per 100 pound animal for total solids with an average of 1.1 pounds, and (2) 78 to 87 percent volatile total solids with an 82 percent average.

To date, little research has been done on the treatment of sheep wastes and,therefore, little information is available. The review of the literature indicates an average daily waste production of 4.0 pounds or 0.06 cubic foot and a total solids content of 29.1 percent for a sheep of about 100 pounds weight. The respective ranges for these values are 1.1 - 7.2 pounds; 0.01 - 0.11 cubic foot; and 23.0 - 36.5 percent total solids (3,23,27,34,84). The approximate density of the waste is 65 pounds per cubic foot and the volatile portion of the total solids is 88 percent (27,34).

Studies on the composition of poultry wastes have been reported by a number of researchers (3,12,23,27,34,49,61,65,84). Average daily waste production of a 4 - 5 pound bird is 0.23 pounds (0.10 - 0.32) or 0.004 cubic foot (0.003 - 0.006). There is a total solids concentration of 30 percent (20 - 45) or 0.06 pounds (0.05 - 0.10) of which 76 percent (65 - 79) is volatile. The figures given in brackets

are the ranges found for the given parameters. Loehr (34) stated that the density of poultry wastes is about 60 pounds per cubic foot. Morris (49) and Dale (12) state that poultry have a daily manure production of approximately 5 - 6 percent of body weight.

The fact that dairy cattle are usually kept close or confined to buildings and are handled daily makes waste data collection from them fairly easy. A summary of several references (12,23,27,28,34,49,61,65, 66,77,78,84) show variations in the parameters involved but the majority of the information was close to the means. Most of the references based on a 1,000 pound dairy cow. Daily manure production was about 8 percent of animal's body weight (34) while the waste density was approximately 61 - 62 pounds per cubic foot (34,61). The average daily waste production is 77 pounds (39 - 100) or 1.3 cubic feet (1.1 - 1.5). The total solids concentration is about 10.0 pounds (4.2 - 12.5) or about 15 percent (7 - 27) of the wastes produced and with a volatile portion of 81 percent (71 - 90). It should also be noted that most of the information is on the Holstein-Friesian breed.

The majority of the waste production data on beef animals is fairly consistent since most of it comes from steer feeding trials (21). Waste production parameters were reported in several references (3,21,32,34, 49,54,84). The mean values (and ranges) obtained from this review will be used in this study. Daily manure production of a 1,000 pound animal is 60 pounds (57 - 61) or 1.0 cubic feet which gives a density of 60 pounds per cubic foot. Thus, the manure production is about 6 percent of animal weight. The total solids concentration is about 15 percent (6 - 20) or 9.0 pounds (8.1 - 9.3) per day per animal. The volatile portion is 78 percent of the total solids. However, it should be noted that Witzel

et al (78), using a 550 pound animal and projecting values to an animal weight of 1,000 pounds, gives a total dry solids production of 3.6 pounds per animal per day with a volatile portion of 88 percent.

2.1.1.1 Plant Nutrient Contents of Livestock Wastes

The total solids portion of livestock wastes are composed of several elements such as carbon, hydrogen, oxygen, nitrogen, phosphorus, and sulphur (56,75). The proportion of each depends primarily on the animal, its age, and diet or ration. Throughout history, livestock wastes have been used for the fertilization of soils to increase plant growth. Table 1 shows the major soil-plant nutrients in animal wastes and the amount of these produced by an average animal.

TABLE 1: MAJOR PLANT NUTRIENTS PRESENT IN LIVESTOCK WASTES.

Animal (weight)	Nitrogen (N) %db	Nitrogen (N) lb/day	Phosphorus (P_2O_5) %db	Phosphorus (P_2O_5) lb/day	Potassium (K_2O) %db	Potassium (K_2O) lb/day	References
Poultry (5 lb)	4.4 (1.8-5.9)a	.0034 (.0012-.0057)	4.0 (1.0-6.6)	.0028 (.0010-.0045)	2.0 (8-3.3)	.0011 (.0005-.0019)	21,34,65,66
Swine (100 lb)	4.3 (3.3-8.6)	.050 (.022-.091)	2.9 (1.6-6.4)	.029 (.015-.034)	3.7 (1.6-4.7)	.041 (.014-.062)	51
Dairy (1000 lb)	3.5 (2.1-6.5)	.36 (.24-.44)	1.1 (1.04-1.1)	.11 (.11-.12)	3.0 b	.31 (.27-.34)	5,21,28,34, 37,65,66,68
Beef (1000 lb)	3.1 b	.29 (.19-.40)	1.1 c	.10 b	3.0 c	.31 c	21,31,34,54, 78
Sheep (100 lb)	5.4 b	.065 d	.34 b	.005 d	1.0 b	.012 d	34

a. Range of data found in references.
b. No range - single or similar values.
c. No data - assume beef values equal to dairy.
d. No data - estimated from % and total solids.

Stewart (63) states that urine contains about one half the nitrogen and about 85 percent of the potassium found in animal wastes while the feces contains the remaining nitrogen and nearly all the phosphorus. Therefore, from the point of view of conservation of plant nutrients, the advantages of collecting all of the wastes for subsequent disposal on the land are apparent.

Besides these major nutrients, there are many minor nutrients present in the wastes. Taiganides and Hazen (66) state that swine manure contains the following amounts of minor nutrients in pounds per ton of waste produced:

(1) calcium (Ca) - 11.3,

(2) magnesium (Mg) - 1.6,

(3) sulphur (S) - 2.9,

(4) iron (Fe) - 0.55,

(5) zinc (Zn) - 0.12,

(6) boron (B) - 0.08, and

(7) copper (Cu) - 0.03.

Taiganides (65) lists the following values for cattle wastes (pounds per ton of waste produced):

(1) Ca - 4.1

(2) Mg - 2.1,

(3) S - 1.4,

(4) Fe - 0.08,

(5) Zn - 0.03,

(6) B - 0.03, and

(7) Cu - 0.01.

Benne et al, as cited by Loehr (34), gives similar values for Mg, Fe and S for cattle. However, they found that the Ca present in dairy cattle wastes (5.6 pounds per ton) was more than twice that present in beef wastes (2.4 pounds per ton). Loehr (34) also cited the work of Benne et

al on the minor nutrients in sheep wastes where Ca, Mg, S and Fe were present at 11.7, 3.7, 1.8 and 0.32 pounds per ton produced respectively. Taiganides (65) found that the manure of hens was very high in minor nutrients as shown by the following (in pounds per ton produced):

(1) Ca - 72.1,
(2) Mg - 5.8,
(3) S - 6.2,
(4) Fe - 0.93,
(5) Zn - 0.18,
(6) B - 0.12, and
(7) Cu - 0.03.

2.1.2 Livestock Waste Management

The management of livestock wastes is complex. The variability that exists in the physical,chemical and biological properties of various wastes is in itself a complicated field of study. However, the need to provide a system of management that is both economical and practical for the livestock producer and yet acceptable from an environmental standpoint, increases the complexity of the problem.

Waste management can be divided into four basic steps: collection or removal, storage, treatment and disposal or utilization (46). Some systems of waste management combine two or more of these steps but in others each step is clearly defined. Many systems of livestock waste management have been proposed and investigated.

Mechanical drying and/or incineration of livestock wastes usually have been found to be too expensive for producer application. Air or bed drying has been successfully used after some other form of pretreatment. In many cases, these processes are odorous and may also contribute to air pollution (23,31,51,65). Composting of livestock wastes has been successful where dry bedding such as straw or shavings are used. The wastes then act as a solid of about 50% dry matter enabling them to be formed into

compost piles (31,51). This practice requires time and equipment for turning the piles periodically and, therefore, is usually not feasible except on a large scale (51). Chemical treatments of animal wastes also seem to be too expensive for practical application (65). Coprophagy or wastelage feeding, which is the utilization of wastes by recycling as a feed to animals of the same or different species and which has been practiced in a very minor manner in the past, has very recently become an active area of investigation (2,15).

Although several other methods of management have been tried, the main processes used in actual practice today are largely biological. There are two basic biological processes for the degradation of waste products - aerobic and anaerobic (10,51).

2.2 Anaerobic Decomposition

Anaerobic decomposition is the breakdown of organic matter by bacteria (anaerobes) whose growth depends largely on the absence of free or dissolved oxygen. Facultative bacteria, which adapt to the presence or absence of dissolved oxygen, may also bring about anaerobic decomposition. (10,18,36,51,56). In this type of environment, the organisms use the oxygen which is bound chemically with carbon, hydrogen and/or other elements in various organic compounds (51). Usually this form of decomposition is associated with the production of strong and sometimes fatal gases and odors (10,18,36,51). Anaerobic decomposition of wastes is the result of usually two groups of bacteria operating simultaneously or in sequence to each other.

The first group, normally facultative, are commonly called "acid formers" and convert the carbohydrates, fats and proteins of the wastes to organic acids, (usually acetic, propionic and butyric),

alcohols, acid carbonates, carbon dioxide and hydrogen sulphide (10,18, 56). This first step, called the "acid phase" is the first stage of decomposition known as the "liquefaction phase" and usually leads to a drop in pH (10). The second step of the "liquefaction phase" is the breakdown of the products of the first step from organic acids and alcohols to ammonia, amines, carbon dioxide, sulphides, acid carbonates and some methane (10,18). The neutralizing effect of ammonia tends to raise the pH of the wastes to about neutral (10).

The second stage is called the "methane" or "alkaline fermentation phase". The methane bacteria responsible for this phase are strict anaerobes. These bacteria are normally very susceptible to high concentrations of volatile acids and operate best at a near neutral pH level (10, 51). Using the end products of the "liquefaction" phase, the methane bacteria produce the final end products of this form of decomposition. These products are humus, methane and carbon dioxide along with ammonia, hydrogen sulphide, hydrogen and nitrogen (10,18). Some organic materials such as lignin are quite resistant to the activity of both groups and may be relatively unaltered at the end of the process (56).

Temperature plays an important role in anaerobic decomposition. Two main temperature ranges exist: (a) the mesophilic range and (b) the thermophilic range (10,19,51,56). The most common in agricultural and domestic waste treatment is the mesophilic one which has a temperature range of 10°C to 42°C (50° - 110°F) with an optimum temperature range of 32°C to 38°C (90° - 100°F). The thermophilic range which usually requires additional heat, has an optimum temperature of 54°C (130°F) with a range of 42°C to 60°C (110° - 150°F) (10,18,51,56). Other factors that affect the process of anaerobic decomposition include the waste's characteristics, rate of loading, effectiveness of mixing, pH and bacterial

population (10).

2.2.1 Anaerobic Decomposition of Livestock Wastes.

Although anaerobic decomposition is usually associated with undesireable odors, the process has certain advantages which should not be overlooked. Loehr (33) states that the purpose of anaerobic treatment is for the destruction and stabilization of organic matter and not for water purification. Muehling (51) also cites Miner who noted that the anaerobic process has the ability to decompose more organic matter per unit volume than an aerobic system. Laboratory trials have not been consistent in their results. Gramms et al (19) found that volatile solids reduction was 17.7 to 26.7% for dairy bull wastes depending on the detention time and daily waste loadings. Using swine wastes, they found a reduction of 49.2% to 60.9% while in poultry wastes, the percentage was 57.0 to 67.8%. Hart (22), using chicken wastes, obtained a volatile solids reduction of 20.4 to 44.8% and, with dairy wastes, a reduction of 10.4 to 16.3% depending on daily loadings and digestor temperatures.

Another advantage of the process is the production of large amounts of methane which, under controlled conditions, may be used as a fuel. Up to 80% of the gas produced by anaerobic digestion may be methane depending on the exact conditions of the process. The remainder of the gas is largely carbon dioxide while the objectionable odorous compounds will contribute approximately 1% of the total volume of gas (51).

Depending on daily waste loadings and detention time, Gramms et al (19) found that, using dairy bull wastes, 61 - 66% of the total gas volume was methane and the remaining percentage was largely carbon dioxide. They also found that the anaerobic digestion of swine wastes produced 58-61% methane while poultry wastes produced 52-58%. Volumes of gas

produced varied from 4.8 to 8.8 cubic feet per pound of volatile solids destroyed for dairy wastes while swine and poultry wastes produced 7.9 to 13.2 cubic feet and 7.3 to 8.6 cubic feet respectively. Hart (22), using chicken wastes, found that gas production was 5.1 to 10.7 cubic feet per pound of volatile solids destroyed, of which 22 to 49% was methane. Using dairy wastes, he found gas production to be 11.0 to 16.2 cubic feet and that 52-64% was methane.

Muehling (51) also states a third advantage to be that the water retention of anaerobic digested wastes is lower than that of undigested wastes. Wastes so treated would dry therefore, much more rapidly.

Intentional and unintentional forms of anaerobic decomposition of livestock wastes in use today are:

(1) anaerobic lagoons,

(2) overloaded aerobic lagoons,

(3) aerobic lagoons with an ice and/or snow cover, and

(4) waste holding systems such as tanks and pits.

Muehling (51) states that Fry (1961) developed a heated anaerobic digestor for livestock wastes in South Africa but promotion in Europe and the United States failed to interest producers. The gas from the digestor was used to furnish heat for the digestor and power for the farmstead.

Loehr and Agnew (32), in laboratory trials, used beef feedlot wastes in anaerobic digestors, heated to 35°C, in which they varied the loading rates. The retention time of the digestors was ten days. They reported the following reductions: (1) for total solids - 55.2, 41.9, 30.7 and 35.8%, and (2) for 5-day biochemical oxygen demand (BOD_5) - 52.4, 57.0, 55.5 and 56.2% for the respective loadings of 0.1, 0.2, 0.3

and 0.4 pound of total solids per cubic foot of digestor per day. Gas production was found to be 7.6, 7.4, 8.7 and 8.5 cubic feet per pound of total solids added and respectively, a methane content of 58, 57, 52 and 53 percent.

2.3 Aerobic Decomposition

Aerobic decomposition is the reduction or breakdown of organic matter by bacteria called aerobes. These micro-organisms require the presence of free or dissolved oxygen as a source of energy for their growth. Facultative bacteria may also utilize free oxygen and act as aerobic bacteria (10, 18, 51). The organic matter is used as a substrate by the bacteria and is broken down into more basic substances.

The original organic compounds of the wastes are decomposed into water, carbon dioxide and ammonia nitrogen along with hydrogen sulphide. As decomposition progresses, the ammonia nitrogen is converted first to nitrites and then to nitrates by the bacteria. Some nitrogen gas is also produced by the process (10, 18). The hydrogen sulphide is also converted, first to sulphur and finally to sulphates. Organic phosphorous, another component of organic matter, is converted to phosphates. However, the production of water and carbon dioxide are the main products of aerobic decomposition (10, 18, 51).

The decomposition of organic matter by aerobic means, is usually less efficient than the anaerobic process. Usually only 40-50% degradation of volatile solids is accomplished by aerobes (51). Dale, as cited by Muehling (51), states that the major benefits of aerobic decomposition are: (1) the reduction in the pollutional characteristics of the wastes; (2) the concentration of minerals which may be readily applied to the land; (3) the destruction of most (possibly all) pathogenic organisms; and (4)

the partial destruction of organic solids into odorless gases. The latter alone may be criteria enough for the use of this system.

2.3.1 Aerobic Decomposition of Livestock Wastes

Since aerobic decomposition is desired largely for its relatively odorless breakdown of organic matter, several researchers have investigated the digestion process over the last few years.

2.3.1.1 Laboratory Research of the Aerobic Process

Dale and Day (11), in their investigation using dairy cow wastes and varying daily loadings, found that the greater waste loadings had a lower breakdown of volatile (organic) solids. The digestors were loaded daily for eleven weeks but operation continued for another thirteen weeks. Organic solids were reduced by 15.5 - 37.5% over the first six weeks; 23.9 - 43% by the end of the loading period and increased to 36 - 51% by the end of the non-loading period. The effluent of the wastes at the end of the twenty-four day period showed an average BOD_5 reduction of 90 percent.

Jones et al (28) conducted a laboratory study using dairy and beef cattle wastes. The manure of a Holstein cow, having a BOD_5 of 19,400 mg/l and a total volatile solids concentration of 50,000 mg/l, was added to aerobic digestors at 125, 150 and 200 ml waste per day. Over a 27 day loading period, BOD_5 reductions were 70, 60 and 76% while the organic solids reductions were 20, 15 and 0% for the respective loadings of 125, 150 and 200 ml per day. The beef wastes used in this study came from a collection pit beneath a slatted floor of a beef fattening unit. The concentration of organic solids and BOD_5 of this waste were 30,000 mg/l and 8,000 mg/l respectively. Using the same loadings as in the dairy research, Jones et al (28) found a reduction of BOD_5 of 59, 70 and 40%

and a volatile solids reduction of 38, 27 and 16% for the 27 day feeding period.

Jones et al (29) also conducted research on the aerobic decomposition of hog wastes. Wastes were added daily to aerobic digestors at a rate equivalent to a hog defecating into 6, 8, 10, 12, 16 and 20 cubic feet of pit volume. This would mean that the smaller volume was more heavily loaded than the larger volumes. The manure used had a BOD_5 of 17,500 mg/l and an ultimate BOD of 54,000 mg/l. The test period ran thirteen weeks which is the average time required for a hog to grow from 70 pounds to 220 pounds liveweight. The first digestor (6 cubic feet/hog) was discontinued after three weeks due to consistent excessive foaming, a sign of overloading (29). The remaining digestors foamed occasionally, usually after daily waste additions, during the first few weeks of operation. At the end of the test period, the remaining digestors had mixed liquor BOD_5's of 2512, 2400, 1700, 2100 and 1710 mg/l and supernatant BOD_5's of 45, 65, 40, 70 and 50 mg/l for their respective loadings on 8, 10, 12, 16 and 20 cubic feet/hog. Jones et al (29) found that mixed liquor BOD_5's were reduced by 81.8 - 86.3%. They also found that oxygen up-take at the end of the period, was 58.9, 45.4, 29.1, 34.8 and 22.2 mg/l/hour for the loading rates on 8, 10, 12, 16 and 20 cubic feet/hog.

Vickers and Genetelli (73), in their investigations, added poultry manure to carboys at the rate equivalent to one pound BOD for volumes of 39 - 233 cubic feet per day. They found an average BOD_5 reduction of 87% and an average solids reduction of 53%. Two other conclusions that they reached were (1) that the minimum value for efficient operation was 60 cubic feet per pound of applied BOD_5 per day; and (2) that aerobic stabilization systems alone were not adequate enough for treating slurries

for surface water disposal.

2.3.1.2 Applications of Aerobic Decomposition

A variety of means have been proposed and investigated to entrain oxygen into the slurry and maintain an aerobic environment for oxidation. The main difference between the systems are the methods used to bring air in contact with the animal wastes for oxygen diffusion.

(1) Simple aerobic lagoons (3, 31, 34, 51, 56)

This process depends on a large water surface for oxygen diffusion from the air into the water. A secondary source of oxygen is the presence of algae which utilize carbon dioxide in the water and return oxygen to it. Since livestock wastes have a high oxygen demand, very large surface areas are required. Although the ponds are very shallow, usually one to four feet in depth, they tend to be facultative near the bottom and, therefore, can very quickly become anaerobic in nature. Winter ice or snow cover, floating liquids such as oil slicks, large algae mats, floating bedding material and other debris decrease the effective surface area and may cause anaerobic conditions. Due to the lagoons' anaerobic tendency and the large surface area required, its use as a single treatment is on the decline.

Microbial action decreases as the environmental temperature approaches freezing. Therefore, little decomposition takes place during the winter months of the more northernly climates. In Alberta, lagoon loading for domestic sewage is 50 pounds BOD_5 per acre per day (82). This is a population

equivalent of 100 per acre. The Canadian Farm Building Code (3) states that for equivalent loadings, one acre would be required for every six cows or 52 hogs for a simple aerobic lagoon. For a combined anaerobic-aerobic lagoon system, the loading rate is 43 cows or 360 hogs per acre on the aerobic lagoon of the system.

(2) Aerated lagoons (13,31,34,51)

This system is similar in principle to that of a simple lagoon. The aerated lagoon usually has a smaller surface area and an increased depth of eight to twelve feet but the decreased area is compensated for by using some mechanical means of adding oxygen. High speed stirring devices and floating aeration sprayers, used to increase the liquid-air surface, and the bubbling of compressed air through liquid manures have been investigated. The amount of aeration will vary depending on the level of treatment desired. A larger quantity of air is required for complete stabilization than for odor control. Problems have been encountered from freezing in winter months. A large amount of solids settle to the bottom where they undergo anaerobic breakdown, usually with a high percentage of solids decomposition.

(3) Other methods of aerobic treatment (7,31,51,72)

Several other methods of introducing air into the slurry of tanks, pits and ditches are used for odor control within a livestock building. The air aspirator involves a pump drawing liquid manure along a suction pipe with air inlet

holes. This allows air to enter the pipe and become entrained in the liquid while, at the discharge end, the slurry is further exposed to air as it falls into the pit. Diffused aeration using bubbling action has also been used but excessive back pressures have been experienced from the clogging of the orifices in the air pipe. Floating aerators similar to those used in aerated lagoons have also been tried.

Another method of aerobic treatment is the use of trickling filters as a component of a waste treatment system. Estimated filter volumes were fairly large, 21 - 77 cubic feet per dairy cow, depending on effluent temperature and BOD_5. Another disadvantage was the estimated required primary and final settling tank volumes of 346 to 391 cubic feet per cow for an effluent BOD_5 of 200 ppm.

Yet another method of aerobic treatment, the oxidation ditch which was developed in Holland, has been investigated quite extensively and will be discussed separately.

2.4 The Oxidation Ditch

The oxidation ditch is a continuous open-channel ditch, usually in the shape of a racetrack, which holds the liquid wastes. These wastes are "stirred" by a rotor which supplies the oxygen for an aerobic environment. The "stirring" or "beating" action of the rotor forces air into the slurry and also moves the liquid wastes continuously around the ditch which prevents the solids from settling to the bottom. This continuous movement brings the wastes back to the rotor for reaeration at

short time intervals (12,49,51,55,84). The oxidation ditch is also known as the aeration or the Pasveer ditch.

2.4.1 Development of the Oxidation Ditch

The oxidation ditch was developed by Pasveer, at the Research Institute for Public Health Engineering (TNO) in the Netherlands, as a low cost method of purifying non-pretreated sewage coming from small communities (49, 51, 55). Muehling (51) cites Pasveer as stating that the oxidation ditch can be used to biologically purify any waste susceptible to aerobic purification.

The principles of rotor aeration go back to 1916 when Haworth in England used large diameter paddles to increase the oxygen supply in water (4). Later Kessener developed the "Kessener brush" which was used in the treatment of activated sludge for over thirty years (4).

While Pasveer was working on the oxidation ditch, two colleagues, Baars and Muskat, tested several different types of rotors. Their investigations (4) covered rotor design operational parameters including speed of rotation, oxygenation capacity, power requirements, rotor diameter, immersion depth and tooth-to-spacing ratio.

2.4.2 The Oxidation Ditch and Livestock Wastes

Due to its simplicity and its odorless process of organic decomposition, the oxidation ditch was quickly adapted by some European livestock producers for treating animal wastes. The first reported use of the oxidation ditch in this field, was in the Netherlands for treating the wastes of a 160 hog confinement unit (51). Dale (12) states that two European farmers achieved good results when mixing four times as much water with the daily waste volume. The first experimental trials using a ditch

located beneath slatted floors were at the Muir of Pert Farms in Scotland (49,51). Both ends of the ditch were exposed to the elements. The rotors were operated intermittently on the basis of six hours on and six hours off. Problems of foaming and anaerobic conditions were experienced (49). Some of the results from other early investigations and field trials are cited by Morris (49) and Dale (12).

Walker and Pos (74) investigated the performance of caged laying hens in buildings where liquid manure storage was achieved using anaerobic storage tanks and within-the-building oxidation ditches. The arrangement of the cages was such that the daily manure load was scraped and added to the pits and ditches as a batch or shock loading. This method appeared to aggravate the problem which the authors experienced with foaming. The presence of feathers, especially during the moulting periods, increased the foam build-up, to the extent that it reached the cages. The attendants in the building, while pleased with the odor reduction did not care for the noise of the rotors or the foaming problem. The layers' performance was slightly better under aerobic conditions than under anaerobic. Average egg production was up from 66.5% to 68.6%; bird mortality was decreased from 10.7% to 9.8% and the feed required per dozen eggs was down from 4.6 pounds to 4.4 pounds for the anaerobic and aerobic conditions respectively.

Jones et al (30) had significant reductions in BOD_5 and total solids in their five trials using within-the-building ditches for hogs. The production of objectionable odors and gases was prevented. Problems from foaming, settling and some ammonia production occurred during the first trials but were remedied during later tests.

Moore et al (45) used a beef confinement unit and an oxidation

ditch having channels ninety feet long, seven feet wide and five feet deep. Only the center portion of about fifty feet was covered by the building while the remainder was outside uncovered. Fairly good results were obtained during a 17-week trial (June-October) which had a ditch loading of 140 cubic feet per animal. The final total solids concentration was 24,000 mg/l (72% volatile) which indicated a reduction of over 50 percent. The remaining solids contained a high percentage of corn which had undergone little degradation. The BOD_5 concentration was 22,000 mg/l which indicated a reduction of 87% by the end of the trial period. Two trials during winter months showed little reduction since the ditch liquid temperatures were near freezing.

In later research, Moore et al (46) reported that, in one trial covering a period from November to June, a constant increase was observed in BOD_5 to about 14,000 mg/l; thereafter the values showed no consistency. Results of a second trial, from October to May, showed that the BOD_5's fluctuated continuously between 900 to 2,500 mg/l. Solids concentrations, however, were fairly constant in both trials, the maximum concentration in the first trial being 118,000 mg/l with 73,000 mg/l in the second.

The Midwest Plan Service (84) lists the following advantages of the oxidation ditch:

(1) decrease in odors during storage and disposal,

(2) decrease in waste volume from partial solids reduction,

(3) decrease in rodent and insect pest infestation, and

(4) ditch and equipment operation and maintenance fairly simple.

The reference also lists several disadvantages:

(1) increased cost for facilities and for operation,

(2) foaming and odor problems if ditch loaded above design conditions or from system failure,

(3) immediate attention required if rotor stops operating, and

(4) few present buildings can be adapted without major construction.

2.5 Biochemical Oxygen Demand

The biochemical oxygen demand (BOD) of sewage, industrial and livestock wastes and polluted waters is the amount of dissolved molecular oxygen required to stabilize the decomposable matter present in water under aerobic conditions (10,59,68,80). This oxygen demand is exerted by three classes of materials:

(1) carbonaceous organic matter usable as a source of food by aerobic organisms,

(2) oxidizable nitrogen derived from nitrites, ammonia and organic nitrogen which serve as food for nitrogen bacteria, and

(3) certain chemical reducing compounds (ferrous ion, sulphite, and sulphide) which will react with molecularly dissolved oxygen (10,80).

Clark and Viessman (10) state that this definition of BOD "is the fruition of over a century of research of a natural phenomenon that is relatively simple in principle yet exceedingly complex in evaluation and instrumentation."

2.5.1 Early Research

As early as 1870, Franklin, cited by Theriault (68), believed that

"The oxidation of organic matter in water is effected chiefly, if not exclusively, by the atmospheric oxygen dissolved in the water." He also believed that if water contaminated with organic matter was kept from air in a carefully stoppered bottle, the gradual decrease in the amount of oxygen in the water was the indication of the oxidation progress of the organic matter. Franklin's studies of the Thames River showed that the oxidation of organic matter proceeded with "extreme slowness".

The research of several other investigators at that time are cited by Theriault (68). Drown (1892) experimented in speeding up the oxidation process by:

(1) exposing samples to air,

(2) aspirating air through samples,

(3) shaking samples, and

(4) exposing samples to air under pressure.

His conclusion was that the oxidation process could not be hastened. Spitta (1900) conducted several experiments which tended to show that the rate of deoxygenation of a polluted water was independent of the amount of dissolved oxygen present. Other researchers in the field found that oxygen demand was not totally independent from organic matter oxidation but certain reducing compounds such as ferrous sulphide also created a demand for oxygen. Other investigators found that nitrogen compounds derived from the oxidation of organic matter also exhibited a demand for oxygen before the organic oxidation was complete.

In 1913, The Royal Commission on Sewage Disposal, as cited by Theriault (68), recommended a dilution method for determining oxygen demand. This method used well stoppered 340-360 cc bottles, completely filled, with an incubation period of five days and at a standard temperature of $18.3^{\circ}C(\pm 1^{\circ})$

This is basically the test used today where 250-300 ml bottles are used at $20^{o}C$ ($\pm 1^{o}$) and a five day incubation period (59,80).

2.5.2 The Nature of the First-Stage BOD Curve

The biochemical oxygen demand of a polluted water breaks down into two stages, the first (or carbonaceous) stage and the second (or nitrification) stage. However, it is only the first stage that appears to be sufficiently constant to be generalized in mathematical terms (18).

During the first stage, the rate of oxidation of organic matter is normally assumed to be directly proportional to the organic matter present. This would suggest that, as the amount of organic matter decreases, the rate at which it is used decreases also (10,18,59,68). Therefore, this statement can be expressed as

$$-\frac{dC}{dt} = k'C$$

where C is the concentration of organic matter present, t is time and k' is a rate constant.

In the first-stage BOD reaction, C is usually replaced by the ultimate BOD (L) less the BOD (Y) at time t. (10,18,59,68). Therefore, as stated by Clark and Viessman (10),

$$\frac{-d(L - Y)}{dt} = k' (L - Y)$$

or,

$$\frac{-d(L - Y)}{L - Y} = k'dt$$

Integrating,

$$-\int_{o}^{y} \frac{d(L - Y)}{L - Y} = k'\int_{o}^{t} dt$$

$$-\ln\left(\frac{L - Y}{L}\right) = k't$$

$$-2.3026 \log \left(\frac{L - Y}{L}\right) = k't$$

$$\log \left(\frac{L - Y}{L}\right) = - \frac{k't}{2.3026} = -0.4343k't$$

If $k = 0.4343k'$, then the relationships may be expressed as:

$$\frac{L - Y}{L} = 10^{-kt}$$

Therefore,

$$Y = L(1 - 10^{-kt}).$$

This equation is the first-stage reaction of the BOD curve.

Practical evaluation of this equation is complicated by the fact that the values of L and k are usually unknown. Theriault, as cited by Fair and Geyer (18), found k to possess a mean value of 0.23 $days^{-1}$ at $20^{o}C$ for domestic sewage. Later investigations gave a mean value of 0.39 with a range of 0.16 to 0.70 $days^{-1}$ at $20^{o}C$. "Lag" periods, caused by inadequate numbers of organisms, may also complicate the estimation of k. A large immediate oxygen demand (IOD) caused by the presence of chemical reducing compounds may result in a "negative lag" period and create complications (10).

2.5.2.1 Estimation of L and k

Since the use of the equation is dependent on knowing the values of L and k for a given waste, it is essential that these values be determined. Several methods for finding the magnitudes of L and k from a series of observations of Y and t have been proposed over the years (10,18). Theriault and Reed (68) developed a set of tables for use in their trial and error method. By approximating L from the observed Y and t values and using

various values of k, they were able to find the k and L values that best fitted their observation for a given waste.

Several other, yet somewhat easier, methods were developed by other researchers in the field of waste disposal. Among these were:

(1) the "log-difference" method developed by Fair in 1936 (17),

(2) the "slope" method developed by Thomas in 1937 (69,70), and

(3) the "method of moments" developed by Moore et al in 1950 (44).

2.5.3 Livestock Wastes and Their BOD

In domestic sewage treatment and disposal, the knowledge of oxygen use by substances in decomposition is important for at least three reasons:

(1) as a generalized measure of the amount of oxidizable matter contained in the water,

(2) as a means of predicting the progress of aerobic decomposition in polluted waters and the degree of self-purification that can be achieved in a given time, and

(3) as a measure of the removal of pollutable matter which accompanies different treatment processes (18).

These reasons are equally applicable to the treatment and disposal of livestock wastes.

Several researchers in livestock waste management have determined values for the standard BOD_5, the ultimate BOD (L) and the rate coefficient (k). However, the values for BOD as reported are not consistent in magnitude nor in the expressed units which may be reported as BOD in

pounds per day, mg per liter (mg/l) or mg per gram (mg/g) solids (volatile or total). This inconsistency makes comparison of data difficult unless other data is also available.

Witzel et al (78), reporting results on a 1,000 pound animal liveweight basis, found that a beef animal waste produced a BOD_5 of 1.02 lb./day (282 mg/g TS) with a k value of 0.089 $days^{-1}$. They also found that the waste of a dairy cow gave a BOD_5 of 1.32 lb.day (194 mg/g TS) while for a dairy bull the value was 0.76 lb./day (180 mg/g TS). The corresponding k values for these wastes were 0.152 and 0.176 $days^{-1}$ respectively. Jones et al (28) reported results of BOD_5 of 8000 mg/l (195 mg/g TS) for wastes of beef steers (850 pounds liveweight) and 19, 400 mg/l (279 mg/g TS) when using dairy cows. Values of BOD_5 were reported by Dale and Day (11) as 25,600 mg/l (198 mg/g TS) or 2.76 pounds/day/head from dairy cows averaging 1500 pounds liveweight.

Jeffrey et al (27) conducted several studies on the manures of swine, dairy cows and sheep but reported k and L values for only a few samples. Four samples of hog manure gave values of L as 490, 367, 633 and 700 mg/g TS with respective k values of 0.068, 0.104, 0.06 and 0.132 $days^{-1}$. Samples of hog urine alone were reported as 403 and 356 mg/g TS for L and 0.084 and 0.117 for k while a single sample of sheep manure was 78 mg/g TS and 0.045 $days^{-1}$ for L and k.

Taiganides and White (67) reported several values for BOD_5, L and k for seeded and unseeded samples of several animal manures. The following is a tabulated summary of their results:

	Seeded			Unseeded		
	BOD_5 (mg/g TS)	L (mg/g TS)	k ($days^{-1}$)	BOD_5 (mg/g TS)	L (mg/g TS)	k $days^{-1}$
Swine	392	1260	0.030	186	298	0.079
Poultry	307	644	0.054	152	198	0.159
Dairy	245	572	0.046	141	426	0.033
Beef	126	*	*	92	*	*
Sheep	113	*	*	80	*	*

* Values for L and k were given as "extremely low".

The following tabulated summary (for seeded samples) was also given by Taiganides and White (67):

	BOD_5 (mg/g TS)	k ($days^{-1}$)	Computed L (mg/g TS)	56-day actual BOD (mg/g TS)
Swine	319	0.110	447	700
Poultry	291	0.121	403	505
Dairy	178	0.061	351	575
Beef	258	0.031	828	605
Sheep	129	0.025	505	475

Other researchers looked at the effect of other variables on BOD. The effect of temperature on ultimate BOD was studied by Ward and Jex (75). They found that, at 20°C, the values for beef manure of L and k were 45,900 mg/l and 0.252 $days^{-1}$. At 10°C and 30°C respectively, the values were 34,500 and 67,900 mg/l for L with corresponding k values of 0.136 and 0.350 $days^{-1}$.

During their research, Taiganides and White (67) stored samples at 2°C if tests were to be completed in two weeks and, for longer periods, the

samples were placed in a freezer. They found that, rather than changing the parameters of the BOD curve, freezing only increased the length of the lag period of the curve. During freezing, the bacteria would be relatively inactive and possibly some would die. After thawing, the organisms would require time to become active and to increase their population. The authors also reported that seeding of frozen and fresh samples with sewage essentially eliminated the lag period and had a significant effect on the BOD_5 values.

Mills and Parker (43), reporting on the effect of the ration on waste BOD properties, found that steers on a concentrate ration resulted in higher k and L values than those on a roughage ration. Using three similar groups of steers, the ten percent dilution of wastes of the group being fed a concentrated grain ration gave a mean BOD_5 of 366 mg/l. A second group on a grain-silage ration had a mean BOD_5 of 214 mg/l while a third group on a grass ration had a mean value of 112 mg/l. The respective k values for these groups were 0.55, 0.43, and 0.25 $days^{-1}$.

2.6 Pollution Potential of Animal Wastes

From the literature reviewed, there would appear to be general agreement that,on the basis of present knowledge, albeit limited, livestock wastes are not a major source of pollution except in those cases where there is either deliberate dumping of wastes into a stream or excessive runoff from large feedlots. However, many authors stress that the potential for environmental pollution from animal wastes is very great and suggest that even minor contamination may be accumulative. Several investigators have used population equivalents (PE) to estimate the magnitude of the problem.

2.6.1 Population Equivalents

Due to the variability of livestock wastes, the average values from the available data are usually used to determine the population equivalents of the various wastes. The equivalents are based on comparison with the properties of domestic sewage. The first values shown in table 2 are the population equivalents determined by Henderson as cited by Eby (16) in 1962. In 1969, Loehr (34) used three values for each animal based on the BOD_5, total solids and nitrogen content of the wastes.

TABLE 2: POPULATION EQUIVALENTS OF ANIMAL WASTES.

Species	Eby (16)	Loehr (34)			Average from Literature Review		
		BOD_5	TS	N	BOD_5	TS	N
man	1	1	1	1	1	1	1
poultry	0.014	0.11	0.09	0.11	0.09	0.11	0.11
swine	1.9	1.7	1.7	1.5	2.0	2.0	1.6
dairy	16.4	8	18	12	11.8	18.2	11.2
beef	16.4	6	18	9	10.0	16.4	9.1
sheep	2.45	-	-	-	0.71	2.2	2.0

This literature review gave similar values to those of Loehr and Henderson. The domestic sewage properties used here as the basis for comparison are:

(1) BOD_5 - 0.17 pounds per capita per day (10,24,34,38,78),

(2) TS - 0.55 pounds per capita per day (10,18,34), and

(3) nitrogen - 0.032 pounds per capita per day (18,34,38).

The value for nitrogen is an average of the values found in the literature.

The average values for nitrogen and total solids of animal wastes have been previously stated. The average value for BOD_5 for each waste was determined averaging the BOD_5 values given as mg BOD/g TS, then converted to pound BOD per pound TS and finally to pounds BOD_5 per animal per day using the average value for total solids for each animal. The following is a summary of the properties - BOD_5 given in pounds per pound TS and nitrogen, TS and BOD_5 given in pounds per animal per day:

(1) poultry - 0.25, 0.0034, 0.06, 0.015;

(2) swine - 0.35, 0.050, 1.1, 0.35;

(3) sheep - 0.10, 0.065, 1.2, 0.12;

(4) dairy - 0.20, 0.36, 10.0, 20; and

(5) beef - 0.19, 0.29, 9.0, 1.7.

Muehling (51) obtained a similar value, 0.32, for the BOD_5 value of swine wastes. The population equivalents as estimated from this literature review are shown in Table 2 under "average from literature review".

2.6.2 The Magnitude of the Animal Waste Problem

Population equivalents are usually used by investigators in the field of animal wastes to determine the pollution potential of livestock as compared to the human population. Townshend et al (72) using the populations in Ontario for 1967 found that the potential pollution load of livestock was 3.4, 6.5, and 3.0 times that of humans for BOD_5, total solids and nitrogen respectively. Projected population figures for 1975 showed little change in these factors.

McQuitty (41) found that the estimated pollution potential of Alberta farm animals and poultry was about 25 times that of the human population of Alberta. The population equivalents used were taken from "Farm Building Standards - Canada" (3) and are those cited by Eby (16). The value for

poultry (0.014) was believed to be too low and the value 0.14 was used. McQuitty also estimated that Alberta livestock produced some 3 million cubic feet of manure per day. This waste production would be approximately 70 acre-feet per day, "assuming no slump".

Population equivalents are based on the properties of domestic sewage and do not include the other factors of human pollution such as garbage and litter. It should be noted also that the equivalent human population of livestock is a measure of the potential and not the actual pollution problem since most of the wastes are recycled via the land for crop utilization.

2.7 Land Disposal of Animal Wastes

Land application of livestock manure has been practised for centuries either directly by natural deposition by animals themselves or indirectly through assisted application by man. This practice was important since these manures were the primary form of fertilizer available. The importance of manures as a fertilizer diminished with the increasing use of readily available and easily applied chemical fertilizers (34). As well as containing soil nutrients, animal wastes also contain organic matter which is eventually decomposed into stable matter or humus. Humus is beneficial in that it increases the water-holding and ion exchange capacities of the soil. Humus also acts as a "cementing" agent by holding smaller clay particles together and therefore increasing the colloidal size of soil particles (8).

However, livestock wastes today are primarily applied in North America to the land as a method of disposal rather than out of any consideration regarding their plant nutrient value or as a soil conditioner.

2.7.1 The Change of Nutrient Properties During Treatment

Laboratory investigations on aerobic and anaerobic decomposition often include measurements of the changes in plant nutrient properties of the wastes. Hart (22) found that little nitrogen was lost during anaerobic digestion, rather the nitrogen became more concentrated and changed in form. Prior to treatment, the nitrogen in poultry wastes was 92% organic and 8% ammonia nitrogen (N_{NH_3}). After the treatment period of 5.5 weeks loading and 3.5 weeks non-loading, there was 30% organic and 70% ammonia nitrogen. In a similar trial (22) using dairy wastes with a nitrogen ratio of 76:24 for organic to ammonia nitrogen, there was a conversion to 50:50 (organic to ammonia) after anaerobic treatment. Gramms et al (19) used dairy bull wastes with 7% ammonia, swine wastes with 21% ammonia and poultry wastes with 44% ammonia nitrogen. They found final concentrations of 16-20% ammonia for the dairy wastes, 42-50% for the swine and 73-75% for the poultry depending on the loading rate and detention time.

Dale and Day (11) reported that the nutrients remaining in dairy waste sludge were 2.37% nitrogen, 0.86% phosphorus and 1.18% potassium after a 7-week aeration period. Bloodgood and Robson (5), using dairy manure, found an identical 3.0% concentration of nitrogen in solids remaining after aeration at 24°C and 4°C. However, it was also noted that nitrogen was reduced by 42% at 24°C and 20% at 4°C. Jones et al (28) found that 26% of the nitrogen, 25% of the phosphorus and 33% of the potassium was lost during aerobic decomposition of dairy manure. Using beef wastes, the respective losses were 30%, 38%, and 21%.

Townshend et al (72) investigated 32 swine installations in Ontario and took grab samples from the various holding tanks being used. The tanks had detention times varying from less than one to six months. This

investigation also included five poultry, three dairy and five beef installations. The following is a tabulated summary of the plant nutrients present and gives the minimum, average and maximum concentrations.

	Nutrient	Concentration (mg/l) Minimum	Average	Maximum
swine	K_2O	330	1850	3520
	P_2O_5	269	2820	5250
	N_T	1500	5700	23000
	N_{NH_3}	1450	3130	7300
	NO_3	0	1.47	4.0
poultry	K_2O	2520	*	3540
	P_2O_5	1480	6520	18000
	N_T	2100	7460	15000
	N_{NH_3}	1700	*	4500
	NO_3	0	*	0.23
dairy	K_2O	690	790	8800
	P_2O_5	305	518	655
	N_T	390	585	3100
	N_{NH_3}	100	256	2700
	NO_3	0.25	1.2	2.4
beef	K_2O	*	774	*
	P_2O_5	570	2660	4700
	N_T	600	2650	4100
	N_{NH_3}	150	856	1350
	NO_3	2.0	3.1	5.6

* No values given.

Hensler et al (25) found nitrogen losses for dairy cow manure to be 2% for an aerobic treatment, 25% for anaerobic and 19% for fermented or piled manure. Much higher losses were found in manure from a beef steer, namely, 32% for aerobic, 30% for anaerobic and 27% for the fermented manure treatments.

2.7.2 Crop Utilization of Nutrients in Animal Wastes

In a greenhouse trial, Hensler et al (25) applied dairy and steer manure to soil intended for a corn crop. Four types of manure from each animal were used, - fresh, fermented (piled), aerobic liquid and anaerobic liquid - and were applied at two rates equivalent to 15 and 30 tons per acre. The manure applications significantly increased corn yields by 1.5 to 3.0 times over the control plot yield. Allowing one week between application and soil incorporation decreased the yield by 5-20%, when compared with yields from plots where incorporation was immediate. The percent recovery of nitrogen by the corn crop was lowest for the aerobic treated liquid - 13% for steer wastes and 16% for dairy. The nitrogen recovery of the other manures ranged from 42 to 47% for dairy and 53 to 66% for the steer wastes with the anaerobic treated liquid being the highest. Percent recovery of phosphorus was 17-25% for dairy and 14-28% for steer wastes. For potassium recovery, the percentages were 44-52% and 34-83% for dairy and steer wastes respectively. In both cases, aerobic treated liquid had the lowest recovery percentage. Recovery percentage was also lowered by delayed soil incorporation which would indicate atmospheric losses.

Similar results were obtained by Witzel et al (78) in earlier trials. Using the same types of manure as Hensler (25), they found N, P and K recovery by corn to be 13-70%, 15-27% and 37-88% respectively for

steer manures. In these trials, fresh manure had the highest and aerobic had the lowest recovery. During trials using dairy manure, recovery was 18-57%, 20-29% and 43-61% for N,P, and K respectively. In the case of nitrogen, aerobic treated liquid had the lowest and fresh manure had the highest recovery percentage. However, anaerobic treated liquid had the highest percentage recovery for P and K while fresh manure had the lowest recovery.

Using forage corn as a crop in a greenhouse trial, Miller et al (42) applied poultry manure to correct deficiencies of zinc and iron in the plant. With a soil containing sufficient potassium,the application of manure at a rate equivalent to 20 tons/acre resulted in a higher yield than the N-P fertilizer used. Addition of manure to the N-P fertilizer increased yield still further but a further application of zinc to this combination showed little yield change. This indicated that the zinc deficiency had been met by the poultry manure. A further increase in yield was noted when additional iron was added to the manure and N-P fertilizer treatment indicating that the poultry manure had not met the iron deficiency.

In field trials, Castle and Drysdale (9) found a substantial yield increase on grass-legume forage crops from the application of dairy feces (no urine) on a low potash soil. The application of dung with increasing amounts of urine showed still larger dry matter yield increases but the highest yield was from an application of urine alone. This increase was five times the yield obtained from feces alone. Addition of potash showed a decrease in the effect of manure application but urine still had the highest yield increase of three times that obtained from feces alone. Although the urine contains most of the potash, the addition of chemical potash to the plots would overcome some of the soil's deficiency. The commercial

fertilizers had yields just below those obtained from urine.

Castle and Drysdale (9) further found a nitrogen recovery of 8% from feces alone and 32% from urine alone. They cite Drysdale's earlier work where a 32% nitrogen recovery from urine was obtained and McAllister's work where a nitrogen recovery percentage of 11% from barnyard manure and 38% from hog slurry was obtained. Castle and Drysdale also reported a direct relationship between the effectiveness of slurry nitrogen (as compared to fertilizer nitrogen) and the percentage of ammonia nitrogen in the total slurry nitrogen.

Stewart (63) states that the effectiveness of animal wastes is usually about 60-80% for nitrogen and 50% for phosphorus when compared to commercial fertilizers. The effectiveness of potassium in manure slurries is similar to that obtained from commercial fertilizers.

In a later article, Stewart (64) states that a twelve week storage period of cow slurry results in a 35% increase in hay yield over unstored manure. On the other hand, a twelve week storage period for hog slurry decreased hay yield by 11% when compared to unstored wastes. Increased yields were also obtained from dilutions of slurry with water. In cattle slurry, the highest yield increase (24%) was obtained from a slurry-water ratio of 1:4 when compared to no dilution. Higher dilutions than this had little increased effect. Using pig slurry, the highest yields were obtained at a slurry-water ratio of 1:2. Stewart also found that three small applications over the growing season had a 23% higher yield than one large spring application even though the same amount of nutrients were added.

2.7.3 Other Factors in Land Application

Zwerman et al (79) investigated the application of dairy manure at 6 tons/acre on the infiltration rate of water during a simulated rainfall

of 2.5 inches/hour. Manure increased infiltration by 27% over the unmanured corn plot. A large 60% decrease in infiltration was observed on a heavily applied chemical fertilizer plot as compared to a manured, moderately applied fertilizer plot. A larger experiment showed that manure did not significantly increase infiltration except on a rotation of wheat followed by four years of alfalfa when infiltration was increased 16%.

McKenna and Clark (39) state that hog wastes applied in the spring and summer are most effective. Summer applications, however, are usually applied to fallow or forage crops since it is not desireable to damage growing crops through the application process. One half of the nitrogen from hog slurries applied in the fall is usually lost by spring while phosphorus and potassium usually remain. Winter application usually results in an average of 60% nutrient losses due to spring runoff, depending on climate and topography. Due to denitrification, a further 20% of the nitrogen may be lost from winter application of hog wastes.

Webber and Lane (76) give minimum land requirements for efficient use of nitrogen by a continuous corn rotation and for maximum application that will not reduce corn yield or cause water pollution. They state that for the most efficient use of nitrogen by the crop, 100 acres is required for each of the following operations:

(1) 100,000 broilers for 10 weeks;

(2) 10,000 layers for 1 year;

(3) 1000 hogs for 175 days;

(4) 200 beef feeders for 1 year; and

(5) 100 dairy cattle for 1 year.

For the maximum application of manure nitrogen, the same size operations would require a minimum of 50 acres to prevent a reduction in crop yield

or to prevent pollution of ground and surface waters from infiltration and runoff.

3. OBJECTIVES

The probability of consequential pollution from animal wastes is rapidly increasing as production units become larger and more concentrated. This problem, combined with the public's increasing awareness of air and water quality, requires a greatly expanded knowledge of the storage, handling, treatment and disposal aspects of animal wastes if economically feasible and ecologically acceptable solutions are to be developed.

The application of sanitary engineering practices are generally not feasible as animal wastes are more concentrated than domestic sewage and are extremely variable in nature as shown in the review of literature. Management of livestock wastes is further complicated in that treatments that are feasible in one area may not work in another due to climate, topography or soil differences.

Therefore, the following objectives were considered in this research project:

(1) to determine the pollution potential of the animal wastes from fattening beef cattle;

(2) to determine the effects of aerobic and anaerobic treatments on the decomposition during storage of these wastes;

(3) to determine the effects of two levels of aeration treatment on the pollution potential of the wastes; and

(4) to determine changes in the major fertilizer nutrient content of these wastes under aerobic and anaerobic storage conditions.

4. EXPERIMENTAL PROCEDURE

4.1 Facilities

4.1.1 Livestock Laboratory Unit

The construction of a Livestock Environmental Engineering Laboratory on the Agricultural Engineering Department's Ellerslie Farm was completed in the early summer of 1969. This laboratory provided an opportunity to study certain aspects of animal waste problems as well as other areas of environmental engineering. This investigation was the first to be undertaken in the new facility.

The building, 100 feet long by 40 feet wide with a 14 feet eaves height, is oriented with its long axis in the north-south direction. The livestock area, 80 feet by 40 feet, is equipped throughout with a concrete slatted floor (figure 1). The north end of the building contains a 10 feet by 40 feet livestock weighing and handling facility while a similar sized area at the south end serves as a feed preparation and storage room. The building is completely insulated.

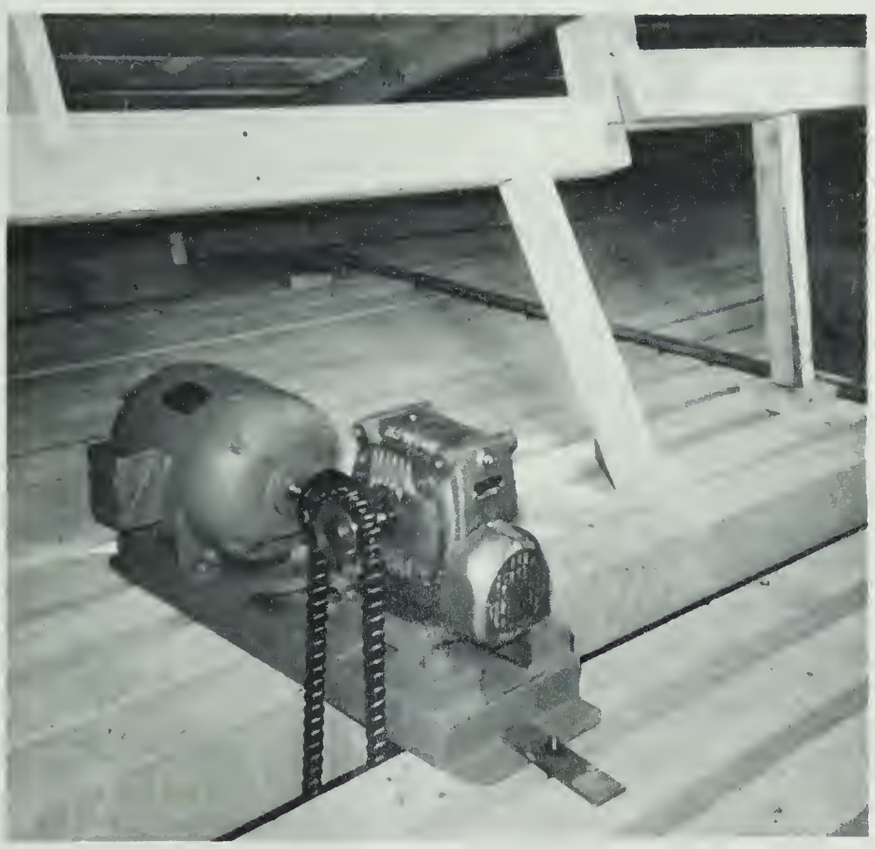
Beneath the slatted floor is a series of pits for the collection and storage of the animal wastes. The building is ventilated by a pressurized system with the exhaust ports located immediately below the slat level. The location of these exhaust ports reduces the amount of noxious gases which may diffuse into the livestock area above.

4.1.1.1 Livestock Pen Layout

In this study, the livestock area was divided into six pens with 10 head of beef fattening cattle per pen. The south half of the building contained two pens of animals on a "solid" floor, consisting of plywood sheeting laid over the slats and bedded on straw. These pens were not included in this study. The north half was divided into two pens (A and B)



Slatted floor with several slats removed for access to pit.



Main rotor drive.

Figure 1.

with free stalls on slats and two pens (C and D) with a totally slatted floor (figure 2). A feedbunk separated the two different systems. This arrangement allowed 22 square feet per head on the slatted floor and 44 square feet per head in the free stall system.

The diagrams in figures 2 and 3 show that the animals in pens B and C occupied the area evenly over pits No. 1 and No. 2 while the area over pits No. 3 and No. 4 was occupied by the animals in pens A and D. The diagrams also show that spillage from the water facilities would be equal in all pits since each pit has one facility located above it.

4.1.1.2 Collection Pits

The liquid manure collection pits beneath the slats are identical in shape and size (figure 3). The depth of each pit is 8 feet from slat level. The center dividing wall is approximately 6 inches wide, 6.5 feet high and extends to within 4 feet from the ends of the pit. The pits are located 10 feet on centers. The actual area of each pit (less the dividing wall area) being 355 square feet.

In pits No. 1 and No. 2, rotors were installed to aerate the liquid wastes to provide aerobic conditions, while pits No. 3 and No. 4 were simply collection-storage pits as would be found in commercial practice and in which conditions are anaerobic.

The aerobic pits were, in fact, oxidation ditches. Curved sheet metal plates were installed in the corners of each of these pits to improve liquid flow characteristics of the slurry as it circulated under the action of the rotors. The sheet metal was screw-fastened to treated fir framing nailed to concrete walls (figure 4).

Since the teeth of a rotor did not reach the bottom of the pit floor in the rotor's vertical position, a two foot depth of water was initially

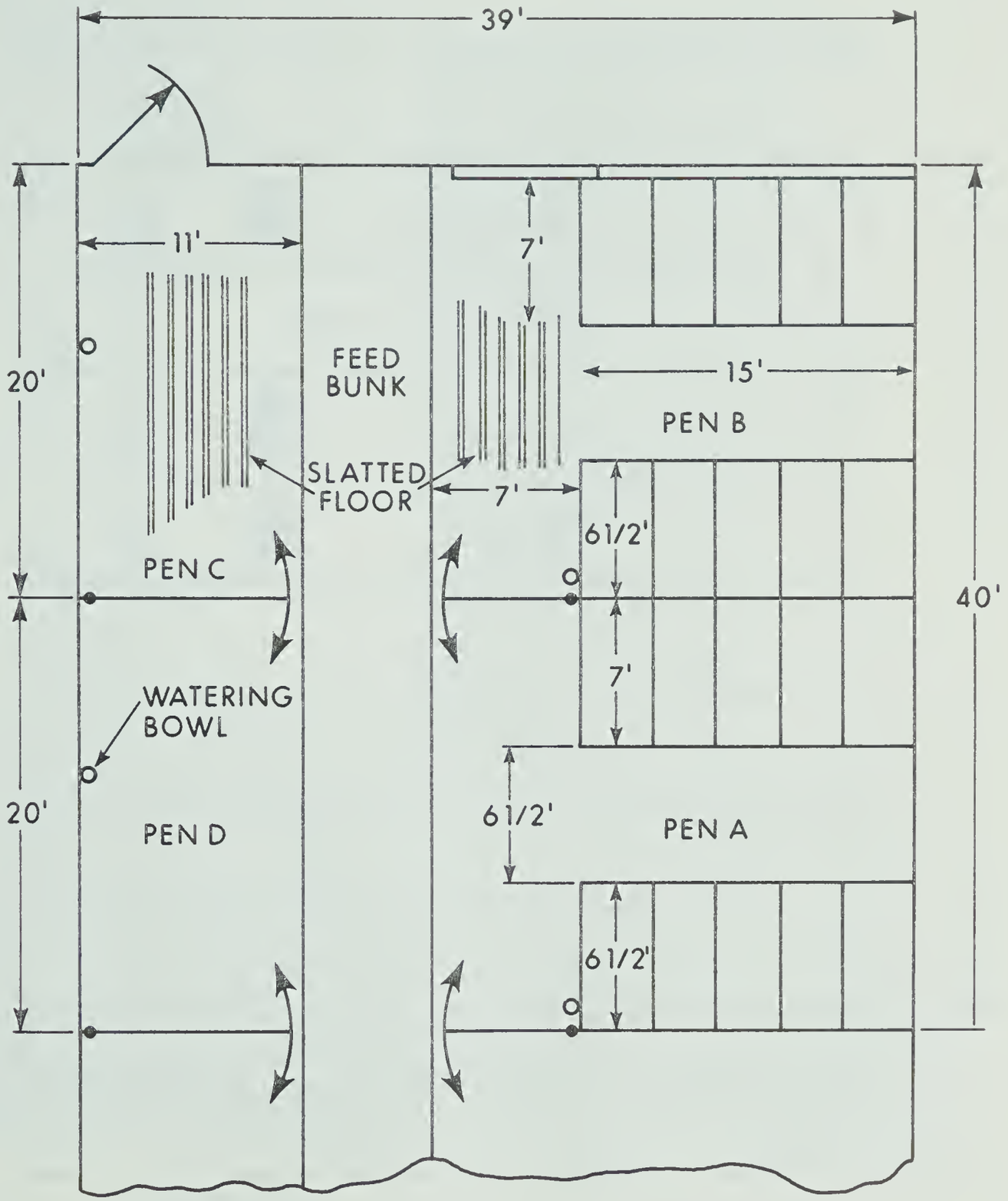


Figure 2: Livestock pens with free stalls to the right and totally slatted floor to the left of feed bunk.



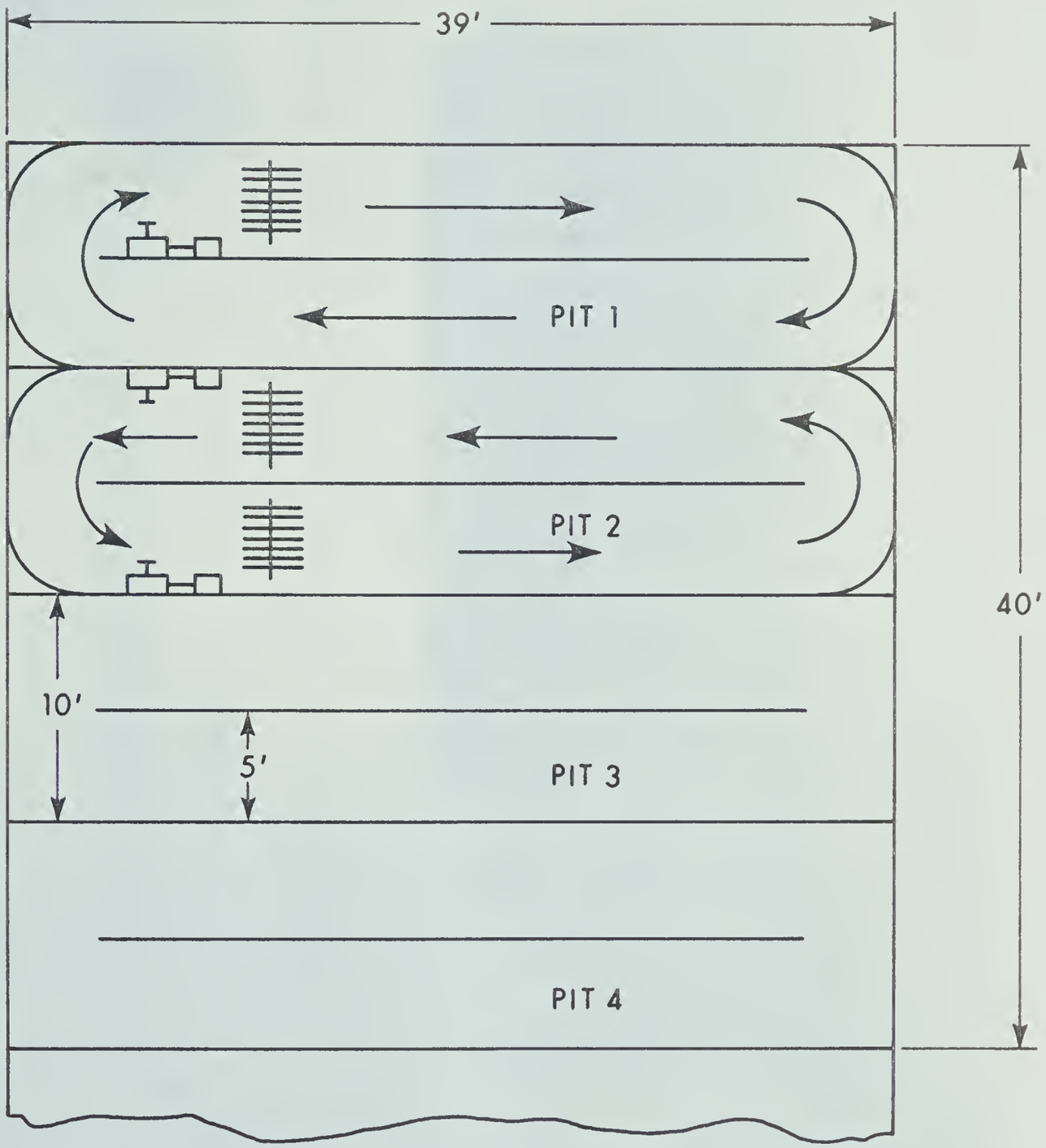


Figure 3: Pit location showing rotor placement in aerobic pits, No. 1 and No. 2.





Figure 4. View of a corner vane used in aerobic pits to facilitate flow of liquid manure.

added to the aerobic and anaerobic pits. The rotors were raised to provide a three to four inch tooth immersion depth. The addition of equal volumes of water provided an equal dilution level for initial conditions in all pits.

4.1.2 The Rotors and Their Placement

The rotors used in this study were designed and constructed by the Department of Agricultural Engineering (47,48). Very few publications reviewed contained any specific information on the design and construction detail aspects of rotors. As the data given by Baars and Muskat (4), in this regard, was the most comprehensive, this was used for the basic rotor design. Each rotor as constructed was 32 inches in diameter and 30 inches in length (figure 5). The rotor blades or teeth were made from one inch angle iron and were 14 inches in length. The teeth were welded to the hollow, 4-inch outside diameter center hub in eight staggered rows of seven and eight teeth per row with the rows spaced 45° apart. The teeth in each row were spaced 3.75 inches on center with a blade-to-spacing ratio of 1:1.5.

Each rotor had to be capable of moving up and down in the vertical plane,depending on the depth of the slurry in the pit, to ensure immersion was maintained within the specified limits of 3 to 6 inches. Therefore, the rotor assembly was designed so it would pivot on a shaft just below slat level and, by means of a cable attached to the lower end of the assembly, be moved through an arc of approximately 70° (figures 6 and 7) In the minimum position, the rotor blades were nine inches from the pit bottom and, in the maximum raised position, were 60 inches. The cable was adjusted by means of a hand winch fastened to the underside of the feed bunk. The pivot shaft of the assembly was fastened to the concrete slats

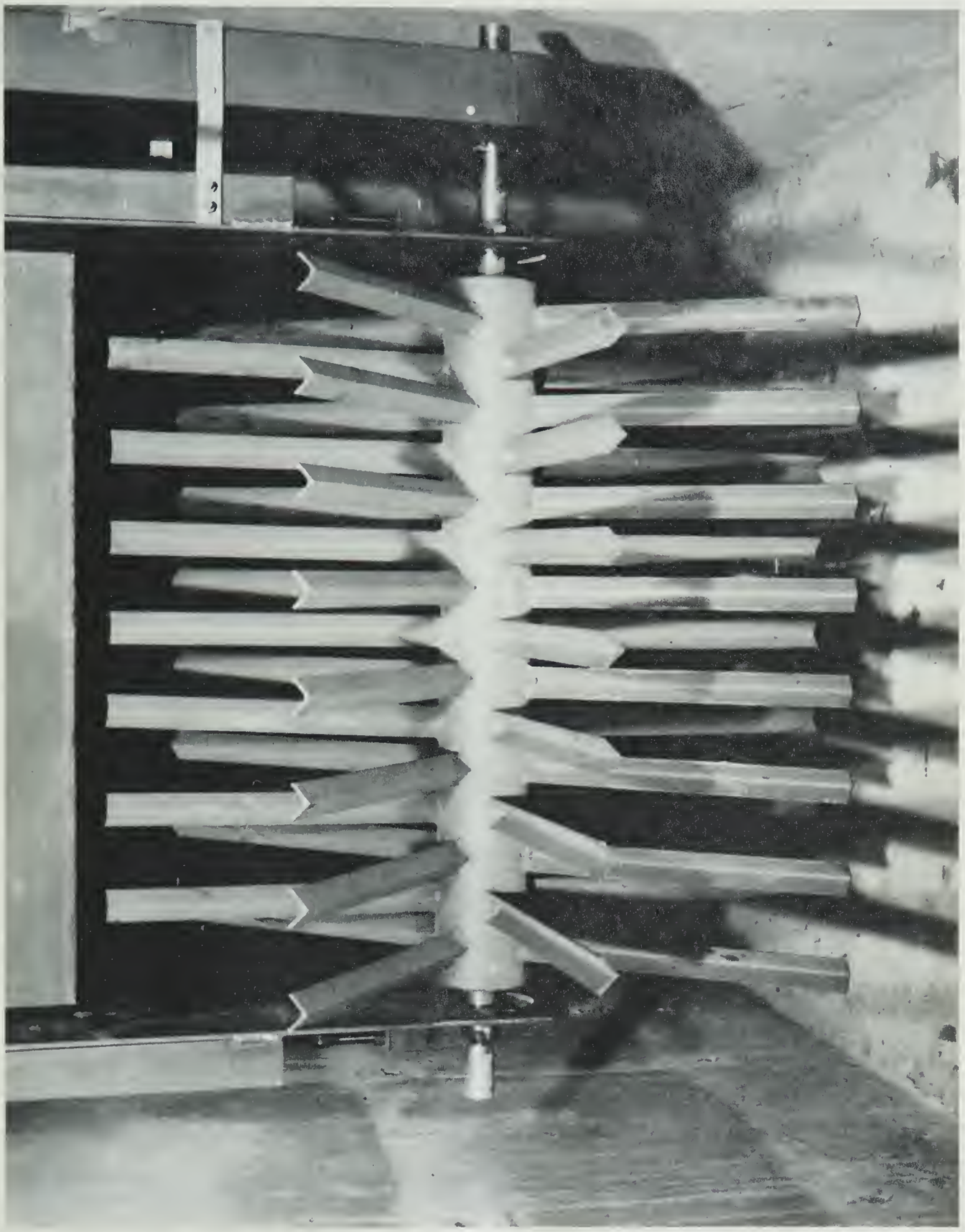


Figure 5. Close-up frontal view of rotor.

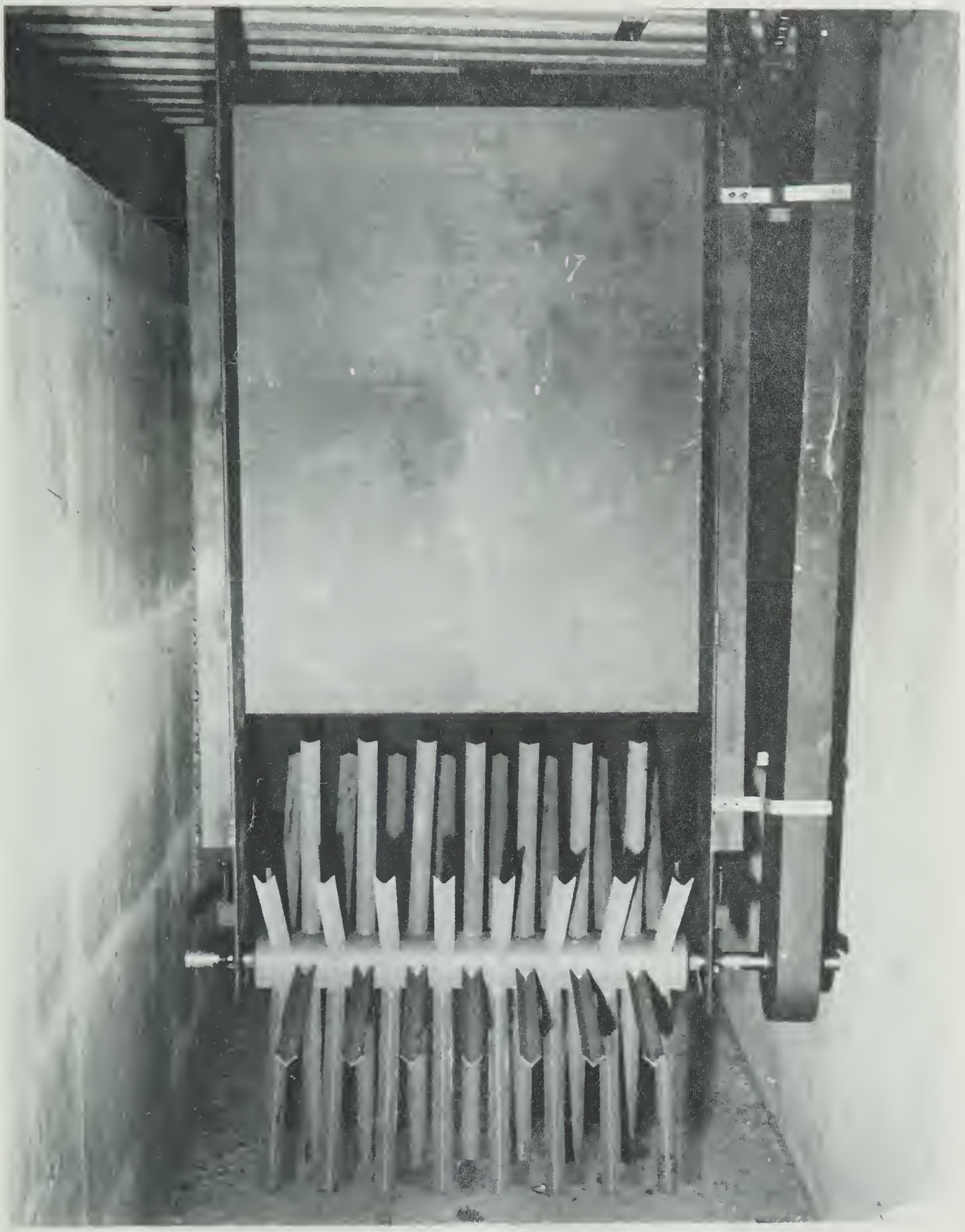


Figure 6. Frontal view of rotor assembly in lowered position.



Figure 7. View of rotor assembly in maximum raised position.

by a bearing pillow block at each end of the shaft (figure 8).

The main drive of the assembly, a 5 hp motor and a reduction gear, was housed beneath the feedbunk (figure 1) with removable panels in the bunk floor for drive maintenance and repair. This placement was necessary so the unit would not interfere with the livestock. One slat beneath the bunk was removed to allow the reduction gear to drive the pivot shaft via a chain drive. This shaft, via a totally enclosed chain drive, drove the rotor (figure 8). The use of the reduction gear and sprocket reduction resulted in a rotor speed of 120 rpm.

One of the objectives of the study was to determine the effects of two levels of aeration treatment. Therefore, a single rotor assembly was placed in pit No. 1 and two assemblies were located in pit No. 2 (figure 3) Since the rotors were in adjacent pits, the disturbance of the livestock for rotor removal and repair was kept to a minimum.

4.1.3 The Livestock

On January 17, 1970, ninety head of beef cattle, purchased by the Agricultural Engineering Department for this and other concurrent projects, were weighed and separated into nine groups. The average animal weight of the pens was fairly even. Four of these groups were to be used for the animal waste project, namely, the animals in pens A, B, C and D. The livestock were put on a grain-haylage ration and the grain was increased over a 12-day pre-trial period until the cattle were on full feed. On January 29, the animals were weighed and the environmental housing trials started. Table 3 shows the initial average weight of the livestock in the four pens used during the waste project.

The livestock were weighed at the end of every four week period. The average weight per head in each pen is shown in table 3 along with total

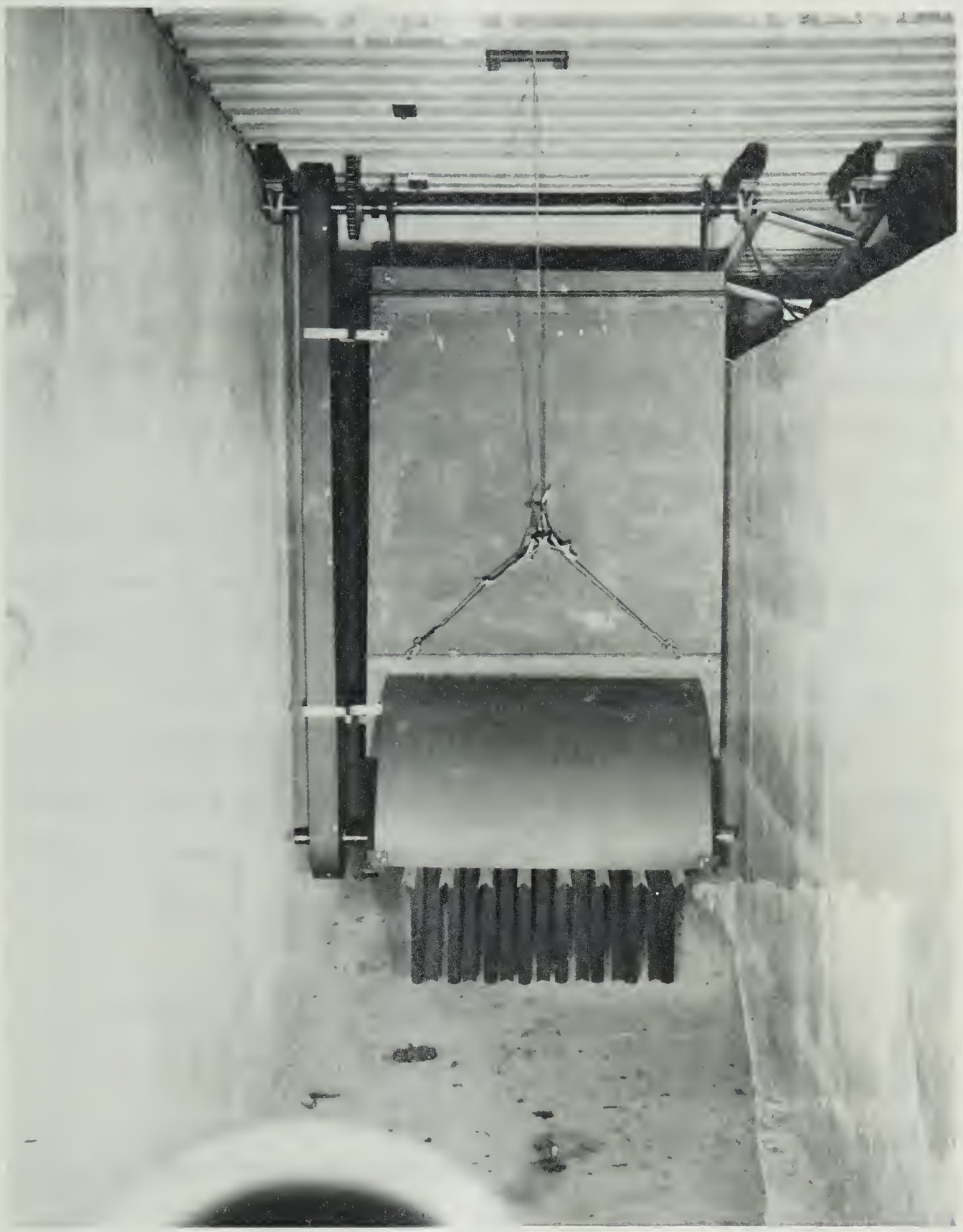


Figure 8. Rear view of rotor assembly showing cable for adjusting assembly to required immersion depth.

grain and total haylage consumed by the animals in that pen over the 28-day period. As shown by the table, the animals in pens A and C were initially on a grain-haylage ration 75:25 while the animals in pens B and D were on a ration of 50:50. The grain-haylage ratio was changed to 85:15 on April 30 for the finishing period.

The cattle in pens C and D were moved occasionally to facilitate the removal and/or repair of rotors. The animals in pen D were moved off their area over pits No. 3 and No. 4 to the south end of the building while the cattle in pen C were moved to pen D. The period of time that the animals were not occupying their respective pens was usually not more than eight hours on any given day. The days that the animals were moved were 29 April; 6, 21 and 29 May; 4, 11, 17, 24 and 26 June and 7 July.

After the weight date, 21 May, the cattle were weighed every 14 days to allow removal of animals that had reached the sale weight of 1,000 pounds. The following shows the sale dates and the number of animals removed for sale:

9 June - Pen A - 1 animal,
Pen C - 2 animals;
23 June - Pen A - 2 animals,
Pen B - 2 animals,
Pen D - 1 animal;
6 July - Pen A - 2 animals,
Pen B - 1 animal; and
21 July - All remaining animals sold.

4.1.3.1 Livestock Feed Rations

Any constituent of a livestock feed may vary considerably in chemical composition depending on factors such as variety, location,

rainfall, fertilization and harvesting practices. Therefore, it is a normal requirement of any trials involving livestock to analyze the feed(s) being used in the ration. Table 5 shows the nutrient contents of the feeds used during the period that this project was being carried out (26, 58). A protein mineral supplement was also used to provide the animals with a balanced ration. The contents of the supplement used is shown in tables 4 and 5. This supplement was fed at the rate of 1 pound per head per day (58).

TABLE 3: LIVESTOCK WEIGHTS AND FEED CONSUMPTION (57).

	Feed Period Ending:	Pen	Average Weight (Lb./head)	Feed (lb./pen) Grain	Haylage
	29 January	A	502	No records for this trial period.	
		B	502		
		C	503		
		D	519		
(1)	26 February	A	568	2952	987
		B	576	2468	2463
		C	556	2511	841
		D	578	2448	2443
(2)	26 March	A	664	4246	1395
		B	646	3315	3310
		C	644	4018	1328
		D	641	3154	3154
(3)	23 April	A	774	4741	1559
		B	738	3755	3755
		C	746	4749	1561
		D	730	3625	3625
(4)	21 May a	A	876	5222	1098
		B	824	4778	1132
		C	847	5117	1073
		D	826	5014	1181
(5)	18 June	A(9)[b]	944	4949	872
		B(10)	918	5190	904
		C(8)	888	4712	823
		D(10)	894	4884	857

Continued

TABLE 3: Continued.

	Feed Period Ending:	Pen	Average Weight (lb./head)	Feed (lb./pen) Grain	Haylage
(6)	16 July	A(5)	980	3620	640
		B(7)	961	4128	732
		C(8)	963	4022	728
		D(9)	939	4559	811
	21 July	A(8)[c]	-	825	145
		C(8)	-	825	145

(a) (i) 28 April - cattle were hormone implanted with 24 mg of Diethylstilbestrol per head, and
(ii) 30 April - ration changed to 85:15 ratio (grain:haylage)

(b) Values in brackets show animals remaining in pen at weigh date. e.g. (9) means 1 animal sold during 28 day period.

(c) (i) Pens combined: 8 head - pen A,
8 head - pen C, and
(ii) Feed records available for pen A; same values assumed for pen C.

TABLE 4: CONTENTS OF PELLETED PROTEIN SUPPLEMENT (57).

Ingredient	lb/ton	%
Barley	719	36.0
Rapeseed Meal	200	10.0
Soybean Meal	200	10.0
Dehydrated Alfalfa	200	10.0
Urea 282%	83	4.1
Sulphur	4	.2
Beet Molasses	100	5.0
Dicalcium phosphate	100	5.0
Trace mineral salt	360	18.0
Vitamin premix[a]	10	.5
Diethylstilbestrol premix[b]	10	.5
Antibiotic premix[c]	14	.7

(a) 10,000 I.U. of Vit. A, 1000 I.U. of Vit. D and 100 I.U. of Vit. E/gm.
(b) 2 grams Diethylstilbestrol per pound; and
(c) Aureofac 10 or TM-10.

TABLE 5: NUTRIENT CONTENTS OF GRAIN, HAYLAGE AND PROTEIN SUPPLEMENT.

	Barley[b]	Haylage[b]	Supplement[c]
Dry matter %	84.4	42.1	72.3
Crude Protein %	11.3	7.6	25.8
Nitrogen[a] %	1.8	1.2	4.1
Phosphorus %	.3	.09	1.3
Potassium %	.6	3.8	.6
Calcium %[c]	.08	1.09	1.5

(a) Nitrogen % = Crude Protein %/6.25 (From Ref. 37).
(b) From Ref. 26 and 58.
(c) Estimated from Ref. 50, 52 and 53.

4.2 Sampling Techniques

Several factors influenced the method of sampling used. The sampling procedure decided upon was to take one composite sample from each pit during each sampling period. Therefore, several grab samples were taken at various locations in the pit being sampled. Samples were processed for BOD analysis on the day of sampling since samples of this nature require cold storage to prevent biological changes which would invalidate other tests. Such storage causes a reduction in microbial activity and consequently would have adverse effects on the accuracy of BOD determinations.

The sampling unit had to be designed so that it would not interfere or alarm the cattle during its operation. Another criterion was that the section of the unit entering the pit had to be less than the slat spacing of 1.5 inches since it was not practical to remove one or more of the 280-300 pound concrete slats for each sample taken.

4.2.1 The Sampling Unit

The sampling unit or probe used in this study is shown in figure 9.

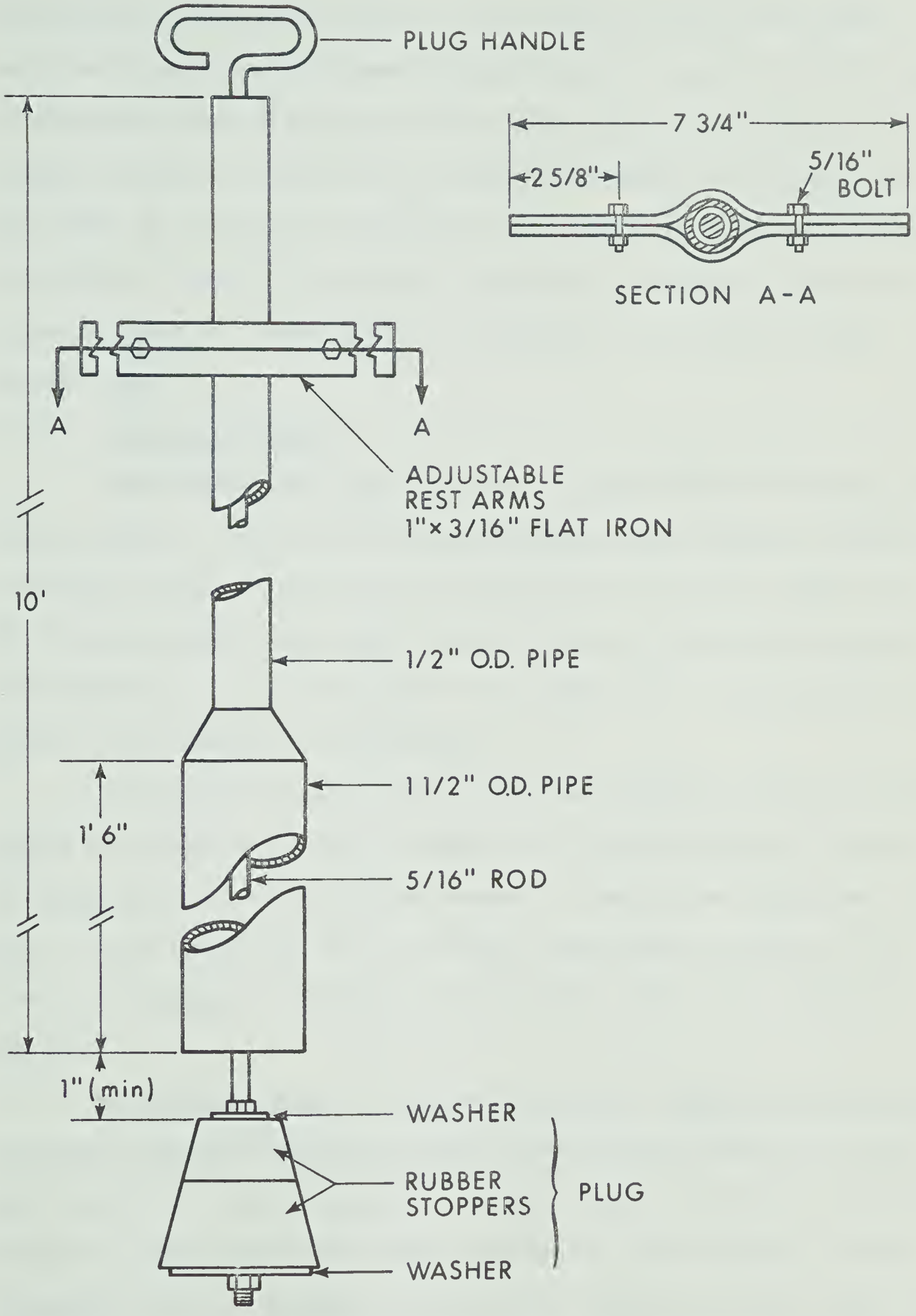


Figure 9: Schematic diagram of sampling probe.



The probe was lowered into the pit in the open position so the slurry could enter the probe as it moved downward into the liquid. When the arms of the probe rested on the slats, the rod was drawn up and the rubber stoppers closed the lower end of the unit. The sample in the probe was then drawn up from the pit and released by lowering the rod, thus removing the stopper. Between the sampling of each pit, the unit was rinsed out either by means of a water hose or by dipping it into a pail of water several times.

4.2.2 Sampling Procedure

Samples were taken from the region one foot above pit bottom to the liquid surface. Usually six to ten grab samples were required to make up a one quart sample, depending on the liquid depth within the sampled pit. The individual grab samples were taken at various locations and collected in a plastic pail, mixed and poured into a glass jar. The samples were then taken to the laboratory for processing.

The livestock occupied the research building over a 185 day feeding period (17 January - 21 July). Samples were taken from each pit from day 79 (6 April) until the cattle were removed. Several more samples were taken over a 24 day period (22 July - 14 August) following the removal of the cattle to determine the effects of decomposition after waste loading had stopped.

Two separate groups of samples were taken. Samples to be examined by standard sanitary engineering tests were collected every six or seven days (table 6). The second group of samples, taken on a 7 or 14 day basis (table 6), were tested by the Alberta Provincial Soils and Feed Testing Laboratory (SFTL) to determine the fertilizer properties of the liquid manure.

As the sanitary engineering test samples were being taken, the

temperature and the depth of the slurry in each pit were also measured and recorded. The liquid depth was measured using a pole (1 inch by 2 inches by 10 feet) marked in one inch graduations. The temperature was measured using a standard laboratory mercury thermometer graduated in $1^{o}C$ units. The data obtained for pit liquid depths and pit temperatures are shown in Appendix V.

TABLE 6: SAMPLING DATES.

Sampling for Sanitary Engineering Lab			Sampling for Soils and Feed Testing Lab		
Date		Day*	Date		Day*
6	April	79			
13		86			
21		94			
27		100	30	April	103
5	May	107	7	May	110
11		114	14		117
18		121			
24		127	28	May	131
30		133	4	June	138
8	June	142			
15		149	18	June	152
22		156			
29		163	2	July	166
6	July	170			
13		177	16	July	180
20		184			
27		191	30	July	194
2	August	197			
8		203	10	August	205
14		209			

* number of test days from 17 January, 1970 (day 0).

4.3 Laboratory Procedures

The one quart samples were taken to the respective laboratories as soon as possible after sampling. Samples were cold stored if they could not be processed immediately since property changes, such as in BOD or pH, could take place otherwise.

4.3.1 The Alberta Soils and Feed Testing Laboratory Tests

These samples were delivered to the S.F.T. Laboratory in the O.S. Longman Building, Edmonton. The tests on these samples were carried out by the laboratory personnel for the author in accordance with the standard procedures used by the laboratory for animal waste samples (1).

Upon receipt of the bulk sample, duplicate samples of 27.5 g were taken from the sample container for nitrogen determination of the slurry. Other samples were removed to determine pH, moisture content and specific gravity. Moisture content was determined by drying samples in an oven at 110°C. Determination of specific gravity was by the weight-volume method. The pH values found for the various samples are given in Appendix I. Dry matter content, as determined from the moisture percentage of the sample, and specific gravity are shown in Appendix I. Samples not immediately processed were stored in a freezer storage unit.

After drying, total nitrogen, phosphorus and potassium contents were determined for the dry matter of the dried material. The amounts of nitrogen present in the liquid and in the dried samples were determined by the Kjeldahl method. Appendix I shows the percentage of nitrogen in the liquid and in the dried samples. The percentage of nitrogen in the

latter is also given on the wet basis. The difference between nitrogen levels in the liquid and the dried sample (wet basis) is the ammonia nitrogen that was lost during drying.

Phosphorus and potassium were removed from the dried samples by digesting the samples using the nitric acid-perchloric acid digestion procedure. The perchloric acid extract, containing phosphorus and potassium, was then diluted before the determinations were carried out. A portion of this extract was then tested for phosphorus by the meta-vanadate method. Extract samples were combined with a reagent of nitric acid and vanadate molybdate and allowed to settle for 30 minutes before reading in a spectophotometer at 400 mμ. Other samples were further diluted and potassium was determined by the atomic adsorption technique. The percentages of phosphorus and potassium on both a wet and a dry basis are given in Appendix I.

4.3.2 Sanitary Engineering Laboratory Tests

The following tests were conducted by the author in the Environmental Laboratory of the Civil Engineering Department, University of Alberta, Edmonton. On the date of sampling, pH readings were taken for each sample and the BOD tests were set up. Samples were then stored in a refrigerator until the tests for oxygen demand index (ODI), total and volatile total solids could be completed.

4.3.2.1 Test for pH

The pH of the samples were obtained by the glass electrode method (80) using a Beckman "Zeromatic II"- model 96A pH meter (figure 10). A sample size of 100 ml was used. The pH of the samples are shown in Appendix II.



Figure 10. Beckman meter used in determination of pH.

4.3.2.2 Determination of Total and Volatile Total Solids (80).

Two volumes (50 ml each) of the liquid manure sample were placed in 100 ml crucibles whose oven dry weights were known. These samples were then dried overnight at 103°C in a Despatch gravity convection oven (figure 11). After drying, the samples were cooled in a desiccator and weighed. The total solids content for each sample was then determined.

The dried samples in the crucibles were then placed in a Blue M "Lab Heat" muffle furnace (figure 11) at a temperature of 600°C for 20 minutes. It should be noted that "Standard Methods" (80) states that ignition time be 60 minutes for samples with a high solids content. However, it was found that practically no change occurred between 20 and 60 minute ignition times. After removal from the furnace, the crucibles were cooled and weighed to determine the fixed total solids. The volatile total solids was the difference between fixed total and total solids. The two individual sample weights were added and recorded as mg/l of total solids and volatile total solids (Appendix II).

4.3.2.3 Determination of Biochemical Oxygen Demand

The BOD test, a bio-assay procedure, is the only test that directly indicates the quantity of oxygen that will be utilized by natural processes in organic matter stabilization. Two methods are available for BOD determinations. The first and most frequently used method is the dilution method (80). This method involves diluting portions of the sample with oxygen-saturated wastes and analyzing for dissolved oxygen after an incubation period, usually five days, at 20°C. However, if samples with a high BOD_5 are to be analyzed in the standard 300 ml bottles, only small volumes of the sample can be used. Sawyer (59)

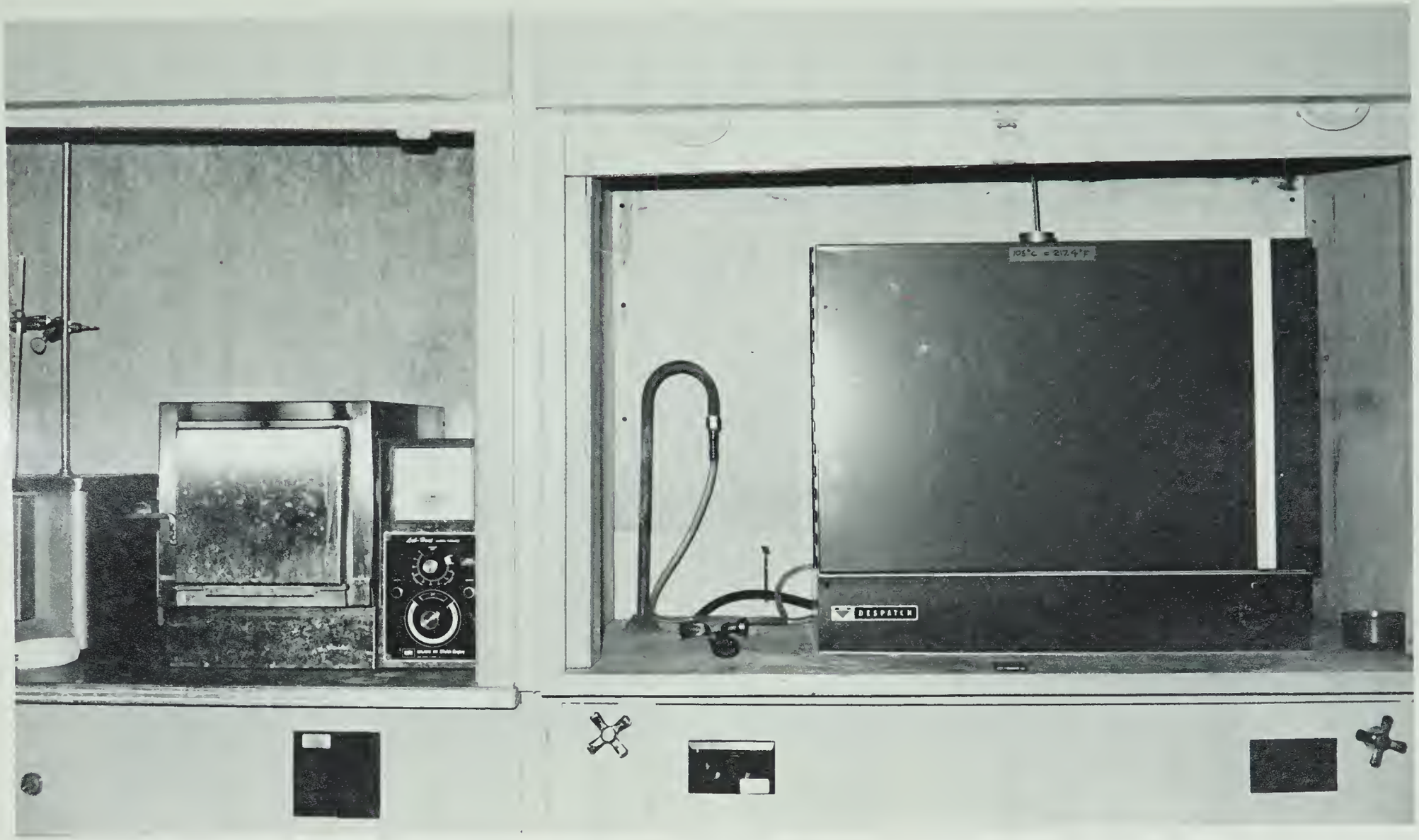


Figure 11. Muffle furnace and convection dry oven on left and right respectively.

recommends 0.1 ml of sample in a 300 ml bottle for samples with a BOD_5 of 6000 - 21,000 mg/l, a strength which would be expected in samples of animal wastes. Consistent and accurate measurement of such a small volume of animal wastes would be practically impossible. Since the dilution method is very sensitive, its operation usually requires a skilled and experienced technician. A second objection to the dilution method is that, for determination of the BOD curve for a given waste, a large number of bottles must be prepared and analyzed. Therefore, for the purposes of this study, the second or manometric method was used.

The manometric method is based on direct measurement of oxygen utilized by a sample under an air or oxygen atmosphere in a closed system with constant temperature and agitation. Oxygen utilization is determined by measuring: (a) the decrease in volume at constant pressure or (b) the change in pressure under constant volume conditions. Another advantage of this method is that it is capable of analyzing wastes with high BOD concentrations.

The Hach Manometric BOD Apparatus (figure 12) was chosen for this study since the system was designed so that trained and experienced personnel were not required. This feature overcame one of the objections against the earlier and more complex Sierp, Warburg and Bancroft apparatuses (71). Tool (71) observed that the Hach apparatus will yield results within $\pm 5\%$ of the standard dilution method. He also stated that this apparatus, by its stirring action and carbon dioxide (CO_2) removal, more closely simulates the actions found in streams and sewage treatment systems.



Figure 12. Hach manometric BOD apparatus showing sample bottle and wick assembly.

The Hach apparatus is operated by taking one volume measurement, size dependent on waste strength, and then a direct reading of the manometer scale, which is calibrated as mg/l BOD. The closed-end manometer is used so that the apparatus is independent of any barometric or temperature change. The oxygen in the air of the closed sample bottle replenishes the dissolved oxygen in the sample as it is utilized by the microbes in the sample. As the oxygen is consumed during organic matter oxidation, CO_2 is released. The system is freed of CO_2 by a wick moistened with potassium hydroxide. The removal of the CO_2 results in a drop in air pressure in the sample bottle which is registered on the manometer. A series of manometer readings plotted on a graph with BOD (mg/l) versus time will give the first stage BOD curve. During the BOD test period (usually five days),the sample is agitated by a magnetic stirring bar (71,83).

In this study, two Hach BOD apparatuses were employed so that BOD tests could be performed on duplicate samples from each pit. This arrangement also allowed one control bottle or blank for each apparatus.

The BOD test procedure used is given in the Hach BOD apparatus manual (83). The apparatus used a volume of 157 ml for direct scale reading but for samples with high BOD values, smaller volumes or sample dilutions or a combination thereof could be used (71,83). For this project, the combination of a sample dilution and a smaller volume was used. A volume of 56 ml per pint (U.S.) bottle was used in Unit A while in Unit B, a volume of 21.7 ml per bottle was used for expected BOD_5 values up to 1400 and 3500 mg/l respectively. Similar volumes of dilution water were placed in the bottles to be used as blanks or controls.

Therefore, the respective conversion factors for these volumes were 4 times and 10 times the scale readings (71). Since the expected BOD_5 values of animal wastes were higher than 3500 mg/l, the dilutions shown in table 7 were used. The dilutions were changed occasionally to allow the maximum use of the scale. Standard dilution water (80) was used from the start of the test period to 29 June and water from the North Saskatchewan River was used from 6 July to the end of the test period. Since river water usually contains all the nutrients and dissolved oxygen required for BOD tests, it is occasionally used in place of the standard dilution water (6).

TABLE 7: DILUTIONS OF WASTE SAMPLES.

BOD Unit	Date	Pit No.	Dilution %	Dilution Factor
A	6, 13 April	1,2,3,4	10	10X
	21 April to 8 August	1,2	20	5X
		3,4	10	10X
B	6 April to 4 May	1,2,3,4	25	4X
	11 May	1,2,3	25	4X
		4	10	10X
	18 May to 8 August	1,2	25	4X
		3,4	20	5X

The BOD samples were prepared on the day of sampling (table 6) and, for the following five days, readings were taken morning and afternoon. The corrected scale readings (sample reading less control sample or blank reading) and the BOD's obtained for each sample are given in Appendix III.

Twice daily an estimate of the temperature of the sample solutions was obtained by reading a thermometer placed in a small flask of water located in the vicinity of the Hach BOD apparatus. The five-day means of these temperatures are shown in Appendix III.

4.3.2.4 Oxygen Demand Index

In 1964, Westerhold documented a procedure for a new waste strength test called the oxygen demand index (ODI) test (6, 60). This test is a modification of the standard chemical oxygen demand (COD) test and uses similar reagents. The ODI test is a chemical oxidation test using potassium dichromate ($K_2Cr_2O_7$) as an oxidizing agent (6, 60).

During the redox reaction, the yellow color of the hexavalent chromate ion ($Cr_2O_7^{--}$) is reduced to the green colored trivalent state (Cr^{+++}) by organic matter. The degree of color change is proportional to the amount of organic matter present in the sample and is measured using a spectrophotometer since the reaction follows the Beer-Lambert Law (60). This law states that the intensity of a ray of monochromatic light decreases exponentially as ion (or color) concentration and length of the light path of the absorbing medium increases (6, 59, 60). Therefore, since the highest intensity in the green-yellow range occurs at 600 mμ, this wavelength was recommended by Westerhold (60). The pure hexavalent (yellow) solution of a blank (control sample), using distilled water in place of a diluted waste solution, is used to set 100%

transmittance on the spectrophotometer. Therefore, any subsequent samples containing organic matter will turn green and absorb a proportion of the 600 mμ light according to the Beer-Lambert Law and the spectrophotometer will give a percent transmittance of less than 100%.

Simpson (60), in his assessment of oxygen demand tests, observed a range of ODI to BOD_5 ratios of 0.61 (final effluent) to 1.24 (raw sewage). He concluded that due to complexity of municipal sewages, no single ODI to BOD_5 ratio can apply to all wastes and therefore, each waste must be analyzed individually. Simpson also stated that, since ODI to BOD_5 ratios were very much similar to COD to BOD_5 ratios, BOD_5 estimations from ODI were as good as those from COD. Therefore, the use of the ODI test would be advantageous since it requires very much less time to carry out than the COD test. Simpson also stated that the ODI test, unlike the BOD test, was less dependent on dissolved solids since boiling acids oxidize all organic matter particles, regardless of size, while dissolved solids are more readily available for organism assimilation than suspended particles.

Initially, in this beef waste study, the procedure used for ODI determination was that advocated by Westerhold (6). It was found that these wastes required fairly large dilutions, usually between 5 and 20%. Due to the dilutions required, two sets of dilutions were made for each pit sample and three aliquots from each set were used for ODI determination. Therefore, six ODI determinations per pit were obtained, from which the mean was used as the ODI test strength for that week's sample. (Appendix II).

Since Westerhold had only calibrated the ODI-transmittance curve to 450 mg/l ODI using standard glucose, a check, using various dilutions

from 1.25 ml to 20 ml of waste per 100 ml of diluted sample, was run to determine if the curve followed the Beer-Lambert Law at high concentrations (low transmittance). The observed transmittances ranged from 1% to 70% but the obtained ODI values for the high waste concentrations were similar to those of the low concentration. Hence, the conclusion was that the curve was linear and followed the law. During the study, dilutions of four to ten percent waste were most commonly used since their light transmittance fell in the recommended range of 20 to 70% which is regarded as the most reliable range of transmittance (6).

The reagents, as given by Westerhold, were later modified to use the standard COD reagents as given by Simpson (60). This modified procedure is shown in Appendix VII. No apparent differences were noted between the respective ODI values obtained during a comparison of the two types of reagents.

5. DATA ANALYSIS AND RESULTS

5.1 Preliminary Treatment of BOD Data

A program was written in Fortran computer language, to determine k (rate constant) and L (ultimate BOD). The program, shown in Appendix VIII, is based on the following methods of determining k and L:

(1) the "log-difference" method developed by Fair (17),

(2) the "slope" method developed by Thomas (69,70), and

(3) the "moment" method developed by Moore et al (44).

Appendix IV gives the k and L values computed by the program. Also included are the values for k_{20} (k corrected to $20^{o}C$) using the temperature correction term as shown in the appendix.

The program was initially unable to handle the BOD data as recorded due to the fluctuations of the readings of the Hach BOD units. Therefore, a logarithmic transformation of the time (in hours) of the BOD readings plotted against BOD (in mg/l) was used to determine the straight line regression of the data (figure 13). The data determined from the regression was then transformed back to the original units to give the "best-fit" BOD curves for the data (figure 13).

The correlation and the regression equation found for each set of BOD values is shown in Appendix III. The correlation between the two variables, log hours and BOD, was found to be significant at the .01 level of probability for 148 of the 150 data sets obtained while the remaining sets were significant at the .05 level.

5.2 Analysis of Rate Constant and Ultimate BOD

The analyses of the computed values for L and k were carried out using analysis of variance procedures (62). The means (Appendix IV) were used since some of the values could not be determined from the obtained

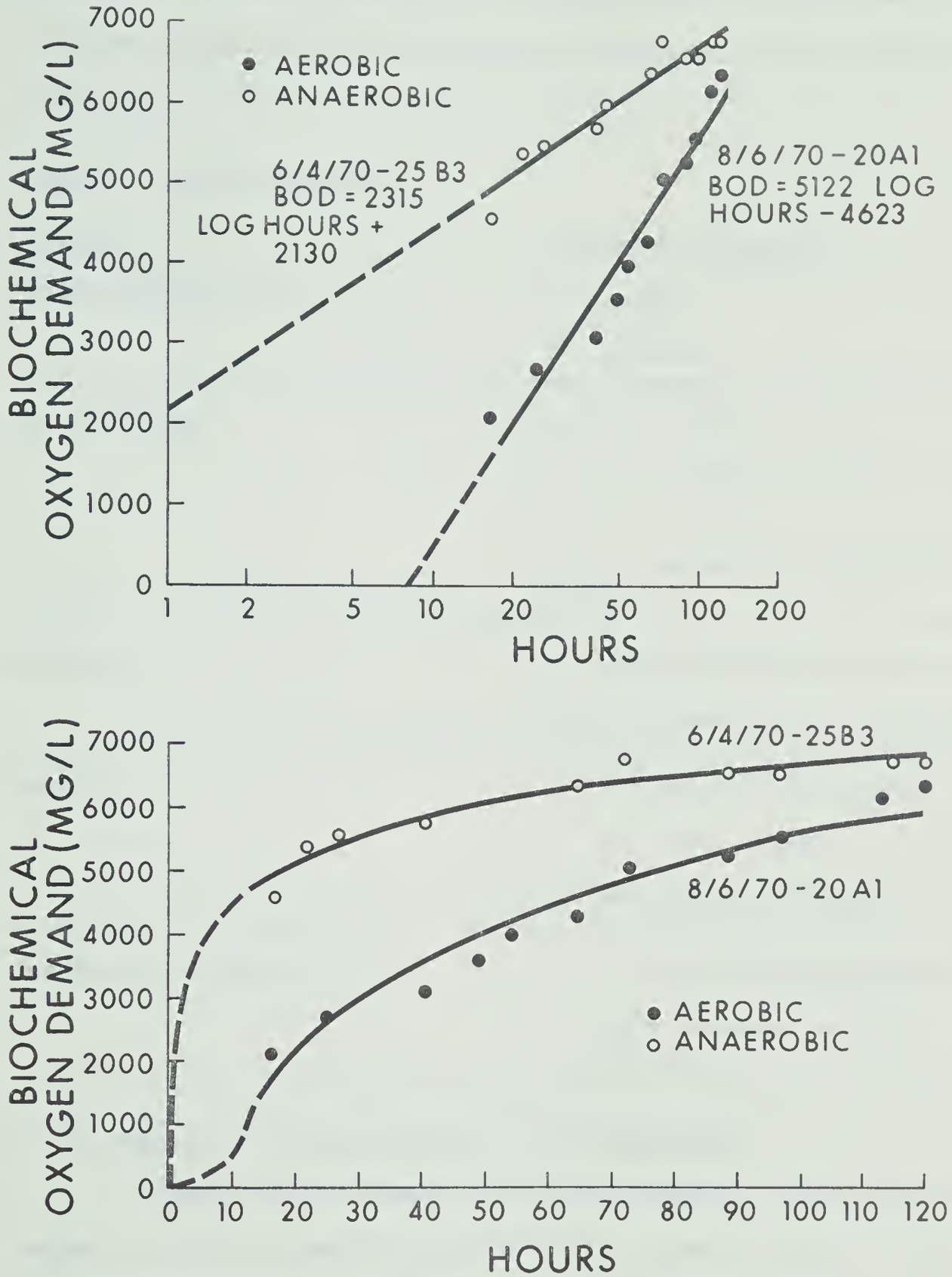


Figure 13: TOP. Logarithmic plots of BOD data with regression equations for an aerobic and an anaerobic pit.
BOTTOM. Arithmetic plots of BOD data for an aerobic and an anaerobic pit.



BOD data and, for this reason, only the main effects of variables are indicated. Table 8 shows the sources of variation and their treatment conditions.

TABLE 8: LIST OF VARIABLES.

Variable	Treatment Condition
Forms of Decomposition	1. Aerobic, 2. Anaerobic.
Pit Treatment	No. 1 - 1 rotor No. 2 - 2 rotors — aerobic No. 3 No. 4 — no rotors - anaerobic
Dilution	1. Dilutions used in Hach unit A, 2. Dilutions used in Hach unit B.
Method	1. LD: log-difference method, 2. S: slope method, 3. MM: method of moments
Temperature Condition	1. k: uncorrected temperature, 2. k_{20}: corrected to $20^{o}C$

5.2.1 Analysis of Variance Results for Ultimate BOD

The analysis of variance comparing the means of the ultimate BOD values for the two forms of decomposition is shown in table 9. The calculated F-value indicated that there was a highly significant difference between the means of L for the two forms of digestion, aerobic and anaerobic.

TABLE 9: ANALYSIS OF VARIANCE - L - DECOMPOSITION FORMS .

Source of Variation	Degrees of Freedom	Mean Squares	F
Between Forms	1	450,670,000	318.47**
Within Forms	22	1,415,100	

** significant at the .01 level of probability.

Analyzing the two forms of decomposition individually gave the results shown in tables 10 and 11 for the aerobic and anaerobic systems respectively.

TABLE 10: ANALYSIS OF VARIANCE - L - AEROBIC .

	Source of Variation	Degrees of Freedom	Mean Squares	F
(a) Pits	Between Pits	1	6,020,800	3.29
	Within Pits	10	1,828,300	
(b) Methods	Between Methods	2	411,670	<1.00
	Within Methods	9	2,715,300	

For aerobic decomposition, there was no significant difference, at the .01 or .05 level of probability, between the means of L for the pits No. 1 and 2. Between the means for the anaerobic pits, No. 3 and 4, similar results were obtained.

TABLE 11: ANALYSIS OF VARIANCE - L - ANAEROBIC.

	Source of Variation	Degrees of Freedom	Mean Squares	F
(a) Pits	Between Pits	1	1,540,800	3.25
	Within Pits	10	474,170	
(b) Methods	Between Methods	2	1,990,000	7.78*
	Within Methods	9	225,830	

* significant at the .05 level of probability.

No significant differences between the means of L, for the methods used for L determination, were found for the aerobic decomposition. However, a significant difference between the three methods was indicated in the anaerobic system.

The means of the anaerobic L values for each method were tested using Duncan's new multiple range test (62) at the .01 level of probability. The results of this test indicated that the overall mean from the method of moments was not significantly different from the means of either the log-difference or the slope methods while the means of the latter two methods were significantly different from each other.

5.2.2 Analysis of Variance Results for Rate Constants

Table 12 shows the analysis of variance comparing the means of the rate constants for the two temperature conditions, uncorrected and corrected to 20°C. The F-value indicates that there was a significant difference between the means of k and k_{20}.

TABLE 12: ANALYSIS OF VARIANCE - k - TEMPERATURE CONDITION .

Source of Variation	Degrees of Freedom	Mean Square	F
Between temperature conditions	1	0.0119070	4.14*
Within temperature conditions	46	0.0028775	

* significant at the .05 level of probability.

Analyzing the means of the rate constant, k, for differences between the two forms of decomposition, showed a highly significant difference between the aerobic and anaerobic treatments (table 13).

TABLE 13: ANALYSIS OF VARIANCE - k - DECOMPOSITION FORMS .

Source of Variation	Degrees of Freedom	Mean Square	F
Between Forms	1	0.0657310	112.27**
Within Forms	22	0.0005855	

** significant at the .01 level of probability.

The analysis of variance for the aerobic means of k (table 14) indicated that there was no significant difference between the two aerobic pits or between the methods used for determining k.

TABLE 14: ANALYSIS OF VARIANCE - k - AEROBIC .

	Source of Variation	Degrees of Freedom	Mean Squares	F
(a) Pits	Between Pits	1	0.0000120	<1.00
	Within Pits	10	0.0002576	
(b) Methods	Between Methods	2	0.0001961	<1.00
	Within Methods	9	0.0002439	

The analysis of variance for the anaerobic means of the rate constants (table 15) showed that the differences between the methods used to determine the constants were highly significant. However, the means of k were not significantly different between the anaerobic pits.

TABLE 15: ANALYSIS OF VARIANCE - k - ANAEROBIC .

	Source of Variation	Degrees of Freedom	Mean Squares	F
(a) Pits	Between Pits	1	0.0006453	<1.00
	Within Pits	10	0.0009244	
(b) Methods	Between Methods	2	0.0039497	17.87**
	Within Methods	9	0.0002210	

** significant at the .01 level of probability.

At the .01 level of probability, Duncan's multiple range test was used to determine the differences between the methods of rate constant determination. The test results showed that the overall mean of k for the slope and moment methods were not significantly different from each other and that both were significantly different from the log-difference method.

5.2.3 Analysis of Variance Results for the Effect of Dilutions on k and L.

The analysis of variance results showing the effects of the dilutions used in this study are given in tables 16 and 19 for the aerobic and anaerobic treatments respectively.

TABLE 16: ANALYSIS OF VARIANCE - DILUTIONS - AEROBIC .

	Source of Variation	Degrees of Freedom	Mean Squares	F
(a) k	Between Dilutions	1	0.0007363	3.26
	Within Dilutions	10	0.0002255	
(b) L	Between Dilutions	1	11,021,000	7.97*
	Within Dilutions	10	1,382,800	

* significant at the .05 level of probability.

For the means of k in the aerobic systems, no significant difference between the two dilutions was indicated. However, the means of the ultimate BOD, L, for the same systems showed that a significant difference between the dilutions existed.

Table 17 shows the analysis of variance comparing the means of L for the four individual aerobic pit dilutions, namely dilutions A and B for Pits No. 1 and No. 2. As shown in the table, a highly significant difference existed between the means of the four pit dilutions.

TABLE 17: ANALYSIS OF VARIANCE - L - INDIVIDUAL AEROBIC DILUTIONS.

Source of Variation	Degrees of Freedom	Mean Squares	F
Between individual dilutions	3	8,083,000	107.78**
Within individual dilutions	8	75,000	

** significant at the .01 level of probability.

The four means of L for the individual aerobic dilutions were tested using Duncan's multiple range test at the .01 level of probability. The results in table 18 show that the mean of Dilution B for Pit No. 2 was significantly different from the other three dilution means.

TABLE 18: AEROBIC ULTIMATE BOD DIFFERENCES.

Pit	Dilution	Mean L (mg/l)
No. 1	A	9200 a[1]
	B	9500 a
No. 2	A	9000 a
	B	12500 b

1 Means followed by same letter are not significantly different at the .01 level of probability.

TABLE 19: ANALYSIS OF VARIANCE - DILUTIONS - ANAEROBIC.

	Source of Variation	Degrees of Freedom	Mean Squares	F
(a) k	Between Dilutions	1	0.0010083	1.14
	Within Dilutions	10	0.0008881	
(b) L	Between Dilutions	1	140,830	<1.00
	Within Dilutions	10	614,170	

For the anaerobic treatment, no significant differences were indicated between the means of the rate constant for the dilutions used. Similar results were obtained for the ultimate BOD means.

5.3 Analysis of Data - Waste Characteristics

Using the analysis of variance procedure, the following characteristics were analyzed:

(a) five-day biochemical oxygen demand, uncorrected for temperature (BOD_{5T}),

(b) oxygen demand index (ODI),

(c) total solids (TS),

(d) volatile total solids (VTS), and

(e) percentage volatile total solids (% VTS).

The Environmental Laboratory data were analyzed comparing the same forms of decomposition and the same pit treatments as given in section 5.2.

The means of the values for the various tested characteristics, obtained over the test period, are shown in table 20.

TABLE 20: CHARACTERISTICS OF THE LIQUID WASTE-CONCENTRATIONS.

	Aerobic		Anaerobic	
Pit Number	1	2	3	4
Characteristic				
BOD_{5T} [1] (mg/l)	6,030	7,460	17,600	16,800
ODI (mg/l)	14,400	16,100	12,800	12,400
Total Solids (mg/l)	95,600	107,300	74,500	66,600
Volatile Total Solids (mg/l)	67,900	76,400	54,200	49,100
Volatile Total Solids (%)	71%	71%	73%	74%
pH	8.0	8.3	6.8	6.8

1 Mean BOD_{5T} temperature = 24.0°C

The curves in figure 14 show the change in the concentration of ODI and BOD_{5T} over the test period including the period following the removal of all the cattle (day 185). The mean values of Pits No. 1 and No. 2 were used to obtain the aerobic curves while the means of Pits No. 3 and No. 4 were used for the anaerobic curves. As shown in figure 14, the BOD_{5T} concentration curve for the anaerobic system was greater than the same curve for the aerobic system while the reverse was found for the ODI concentration curves.

Figure 15 shows the curves obtained for TS and VTS concentrations for both forms of decomposition. As with the ODI curves, the aerobic treatment had a greater concentration of TS and VTS than the anaerobic system.

5.3.1 Analysis of Variance Results - Concentrations

Table 21 gives the analysis of variance results of the comparison between aerobic and anaerobic forms of decomposition. A highly significant difference is shown to exist between the two forms for the concentrations of BOD_{5T}, ODI, TS and VTS. Similar results were obtained for percentage VTS.

For the aerobic and anaerobic treatments respectively, tables 22 and 23 give the results of the analysis of variance for the comparison of pit concentrations within the two forms of decomposition.

For the pits of the aerobic system, no significant difference is shown to exist between BOD_{5T} or ODI. Although there was no significant difference between the percentage of VTS, a significant difference in the concentrations of TS and VTS existed between Pits No. 1 and No. 2.

In the anaerobic system, for the five variables tested, BOD_{5T}, ODI, TS, VTS and percentage VTS, no significant differences were observed between Pits No. 3 and No. 4.

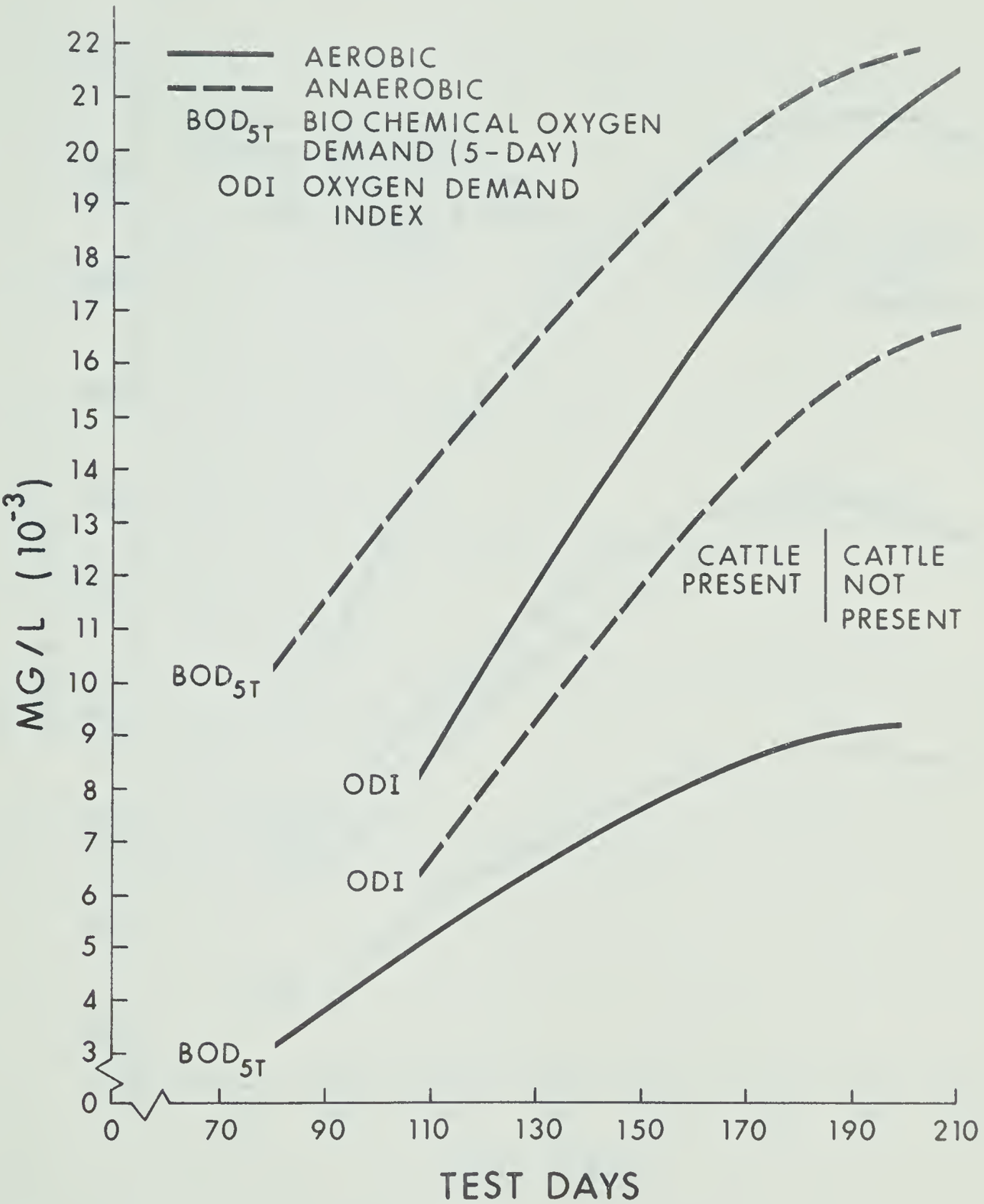


Figure 14: Graph illustrating the change in BOD_5 and ODI (mg/1) over the test period for the aerobic and anaerobic treatments. Finished animals were removed from pens from day 143 to day 185, after which all pens were vacated.



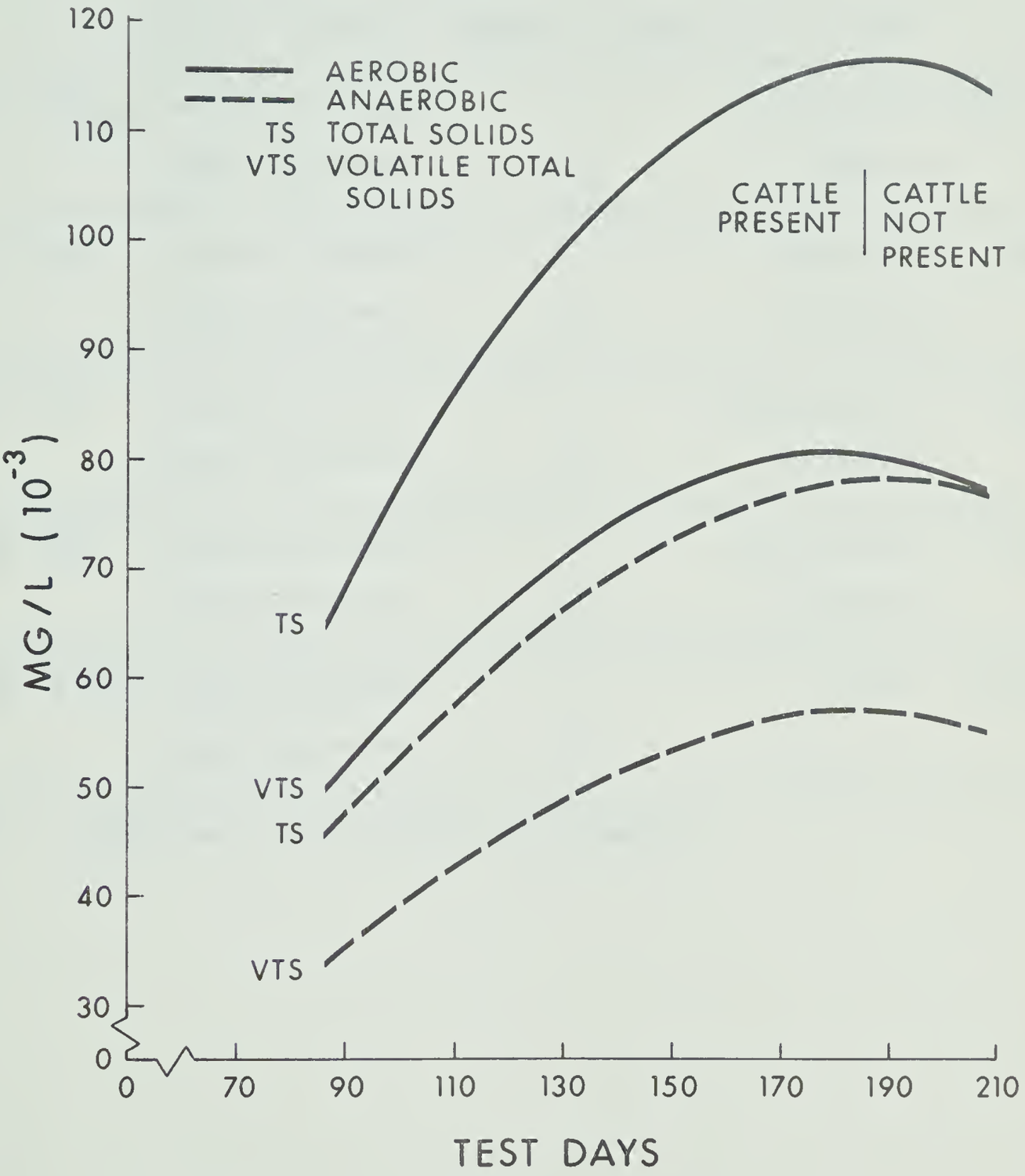


Figure 15: Graph illustrating the change in TS and VTS (mg/l) over the test period for the aerobic and anaerobic treatments. Finished animals were removed from pens from day 143 to day 185, after which all pens were vacated.



TABLE 21: ANALYSIS OF VARIANCE - WASTE CHARACTERISTICS (MG/L) FOR AEROBIC AND ANAEROBIC TREATMENTS.

		Source of Variation	Degrees of Freedom	Mean Squares	F
(a)	BOD_{5T}	Between Treatments	1	2,068,400,000	188.94**
		Within Treatments	74	1,094,700	
(b)	ODI	Between Treatments	1	185,300,000	9.99**
		Within Treatments	62	18,547,000	
(c)	TS	Between Treatments	1	21,304,000,000	77.94**
		Within Treatments	70	273,320,000	
(d)	VTS	Between Treatments	1	9,236,700,000	79.24**
		Within Treatments	70	116,560,000	
(e)	% VTS	Between Treatments	1	146.49	19.11**
		Within Treatments	70		

** significant at the .01 level of probability.

TABLE 22: ANALYSIS OF VARIANCE - WASTE CHARACTERISTICS (MG/L) FOR AEROBIC TREATMENTS.

	Source of Variation	Degrees of Freedom	Mean Squares	F
(a) BOD_5T	Between Pits	1	19,541,999	3.77
	Within Pits	36	5,176,800	
(b) ODI	Between Pits	1	27,195,000	1.20
	Within Pits	30	22,745,000	
(c) TS	Between Pits	1	1,400,000,000	4.61*
	Within Pits	34	303,500,000	
(d) VTS	Between Pits	1	680,340,000	5.74*
	Within Pits	34	118,480,000	
(e) % VTS	Between Pits	1	0.694	<1.00
	Within Pits	34	9.305	

* significant at the .05 level of probability.

TABLE 23: ANALYSIS OF VARIANCE - WASTE CHARACTERISTICS (MG/L) FOR ANAEROBIC TREATMENTS.

		Source of Variation	Degrees of Freedom	Mean Squares	F
(a)	BOD_{5T}	Between Pits	1	5,929,000	<1.00
		Within Pits	36	16,618,000	
(b)	ODI	Between Pits	1	781,250	<1.00
		Within Pits	30	14,653,000	
(c)	TS	Between Pits	1	529,000,000	2.61
		Within Pits	34	202,510,000	
(d)	VTS	Between Pits	1	215,110,000	2.26
		Within Pits	34	95,155,000	
(e)	% VTS	Between Pits	1	6.67	1.04
		Within Pits	34	6.40	

5.3.2 Analysis of Variance Results - Quantities.

Unlike domestic or municipal sewage where the degree of dilution is fairly constant, the amount of dilution of livestock wastes may vary considerably and comparison of animal wastes with widely different dilutions may result in erroneous conclusions. Therefore, the quantities of the variables, BOD_{5T}, ODI, TS and VTS, were determined from the variable concentration and the pit volume (Appendix 9).

Table 24 shows the mean quantity of each variable present in the four pits. For ODI, TS and VTS, the average quantities in each pit were similar while the amounts of BOD_{5T} in the anaerobic pits were three to four times that found in the aerobic pits.

The analysis of variance results in table 25 show that no significant difference existed between the aerobic and anaerobic forms of decomposition for the quantities of three of the variables, ODI, TS and VTS. However, for the fourth variable, BOD_{5T}, the difference in the amount between the two treatment systems was highly significant.

Table 26 gives the analysis of variance results for the comparison between the two aerobic pits. No significant differences between Pits No. 1 and No. 2 were found to exist for any of the four variables.

When comparing the two anaerobic pits, No. 3 and No. 4, results similar to those found for the aerobic system were noted (table 27).

TABLE 24: MEAN QUANTITIES OF WASTE CHARACTERISTICS PER PIT.

Pit Number	Aerobic 1	2	Anaerobic 3	4
Characteristic				
BOD_{5T}[1] (lb)	352	401	1330	1280
ODI (lb)	852	885	989	984
Total Solids (lb)	5690	5880	5600	5090
Volatile Total Solids (lb)	4020	4180	4090	3780

TABLE 25: ANALYSIS OF VARIANCE - WASTE CHARACTERISTICS (LB/PIT) FOR AEROBIC AND ANAEROBIC TREATMENTS.

	Source of Variation	Degrees of Freedom	Mean Squares	F
(a) BOD_{5T}	Between Treatments	1	16,700,000	149.07**
	Within Treatments	74	112,300	
(b) ODI	Between Treatments	1	221,500	2.14
	Within Treatments	62	103,560	
(c) TS	Between Treatments	1	3,440,500	2.22
	Within Treatments	70	1,545,600	
(d) VTS	Between Treatments	1	497,000	<1.00
	Within Treatments	70	721,480	

** significant at the .01 level of probability.

TABLE 26: ANALYSIS OF VARIANCE - WASTE CHARACTERISTICS (LB/PIT) FOR AEROBIC TREATMENTS.

		Sources of Variation	Degrees of Freedom	Mean Squares	F
(a)	BOD_{5T}	Between Pits	1	22,908	1.39
		Within Pits	36	16,525	
(b)	ODI	Between Pits	1	8,745	<1.00
		Within Pits	30	68.081	
(c)	TS	Between Pits	1	329,670	<1.00
		Within Pits	34	775,450	
(d)	VTS	Between Pits	1	220,270	<1.00
		Within Pits	34	302,800	

TABLE 27: ANALYSIS OF VARIANCE - WASTE CHARACTERISTICS (LB/PIT) FOR ANAEROBIC TREATMENTS.

		Sources of Variation	Degrees of Freedom	Mean Squares	F
(a)	BOD_{5T}	Between Pits	1	14,842	<1.00
		Within Pits	36	212,702	
(b)	ODI	Between Pits	1	276	<1.00
		Within Pits	30	145,640	
(c)	TS	Between Pits	1	2,368,500	1.02
		Within Pits	34	2,327,300	
(d)	VTS	Between Pits	1	887,990	<1.00
		Within Pits	34	1,150,000	

5.3.3 Multiple Regression - Estimation of BOD_5.

The time required for the biochemical oxygen demand test often puts the test at a disadvantage. When releasing a quantity of treated waste (livestock or municipal) or determining the efficiency of a treatment system, five days are required to determine the BOD_5. One method of approximating BOD_5 is the 2.5 day - 35°C BOD (71) but the time factor again may be too long. Therefore, multiple regression equations, using one or more variables to determine BOD_5, were determined.

Only the variables, TS and ODI, were used as the independent variables with BOD_5 as the dependent. The reasons for doing so were that the tests for ODI and TS are fairly rapid and simple to run and the equipment required for these tests normally will be available in any laboratory. The test for VTS also was considered but laboratories for the most part do not have access to the necessary muffle furnaces. A further reason for using only two variables and their interaction was to keep the regression equation as simple as possible.

Although the analyses, due to the nature of the project, would not show a relationship between ODI and BOD_{5T}, highly significant simple correlations at the .01 level of probability existed between the two variables for both aerobic and anaerobic treatment systems. Slightly lower correlations between BOD_5 and TS were observed but they were still significant at the same probability level. A relationship is known to exist between BOD_5 and TS since organisms largely use the dissolved organic portion of TS for food (18).

To determine the relationship between the dependent and the independent variables, a computer program (20) for a stepwise multiple regression was used.

The general model considered for the multiple regressions was as follows:

$$Y = A + B_1X_1 + B_2X_2 + B_3 \frac{X_1}{X_2}$$

where Y = dependent variable, BOD_5 (mg/l),

X_1 = ODI (mg/l),

X_2 = TS (mg/l),

A = intercept,

and $B_1 \ldots B_3$ = multiple partial correlation coefficients.

5.3.3.1 Multiple Regression - Estimation of BOD_5 - Aerobic Treatment.

The data for BOD_{5T}, ODI and TS, in mg/l, from the aerobic pits, No. 1 and No. 2, were used to determine the multiple regression shown in table 28. Only the data for days 107 to 203 were used since some of the values for one or more of the variables were missing on the other test days (Appendices II and III).

The interaction of ODI and TS accounted for an additional reduction of 0.2% in the sum of squares while the addition of the variable VTS only accounted for a further 4.0%. Therefore, only the independent variables, ODI and TS, were used.

TABLE 28: REGRESSION ANALYSIS FOR AEROBIC BOD_5.

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Squares	F
Attributable to Regression	2	90,987,120	45,493,552	32.89**
Deviation from Regression	27	37,344,016	1,383,111	
Total	29	128,331,136		

Cont'd.

TABLE 28: (continued)

Regression Equation:

$$BOD_5 = -2970 + 0.219\ (ODI) + 0.0660\ (TS)$$

Multiple Correlation Coefficient = 0.836

Cumulative Proportion of Sum of Squares Reduced = 0.709

Standard error of the Estimate = 1197 mg/l

** significant at the .01 level of probability.

As shown in table 28, the multiple correlation coefficient of 0.836 indicated a good relationship between the dependent variable, BOD_5, and the selected independent variables, ODI and TS. The standard error of the estimate indicated that BOD_5 could be estimated to within $\pm$1197 mg/l using the regression coefficients obtained.

The reduction in sum of squares due to regression was highly significant as indicated by the F-value for the regression's analysis of variance.

Since the equation is not valid beyond the range of the independent variable(s) data used for its determination, the ranges used were:

(1) TS: 62,000 to 139,500 mg/l;

(2) ODI: 7,200 to 23,800 mg/l.

5.3.3.2 Multiple Regression - Estimation of BOD_5 - Anaerobic Treatment.

Using the BOD_{5T}, ODI and TS data, in mg/l, obtained for the anaerobic pits, No. 3 and No. 4, the multiple regression shown in table 29 was determined. The same time sequence was used as for the aerobic determination. The ranges of the independent data used in this equation were:

(1) TS: 38,000 to 97,000 mg/l;

(2) ODI: 5,400 to 20,300 mg/l.

TABLE 29: REGRESSION ANALYSIS FOR ANAEROBIC BOD_5.

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Squares	F
Attributable to Regression	3	189,964,016	63,321,328	19.82**
Deviation from Regression	26	83,043,600	3,193,984	
Total	29	273,007,616		

Regression Equation:

$$BOD_5 = 4540 + 0.279\ (ODI) + 0.0957\ (TS) + 23100\ (\frac{ODI}{TS})$$

Multiple Correlation Coefficient = 0.821

Cumulative Proportion of Sum of Squares Reduced = 0.696

Standard Error of the Estimate = 1852 mg/l

** significant at the .01 level of probability.

The interaction between ODI and TS used in this regression only accounted for an additional 0.2% reduction in the sum of squares. However, its inclusion in the equation reduced the intercept from 8080 to 4540. The addition of the variable, VTS, only provided a further reduction of 1.0%. The practical significance of including VTS and its interactions with the other independent variables, was considered to be negligible.

5.4 Analysis of Data - Waste Nutrients.

The analysis of variance procedure was used to compare the forms of decomposition and the pit treatments as given in section 5.2, for the following nutritive characteristics:

(a) dry matter (DM),

(b) total nitrogen (N_T),

(c) organic nitrogen (N_0),

(d) ammonia nitrogen (N_{NH_3}),

(e) phosphorous (P), and

(f) potassium (K).

Shown in table 30 are the means of the concentrations obtained for these characteristics over the test period (Appendix I). In addition, the means for the properties, specific gravity and hydrogen ion (pH), are also given.

TABLE 30: NUTRITIVE CHARACTERISTICS OF THE LIQUID WASTE CONCENTRATIONS.

	Aerobic		Anaerobic	
Pit Number	1	2	3	4
Characteristic				
Dry Matter (%)	9.4	10.6	6.9	6.3
Specific Gravity	1.027	1.026	1.015	1.017
pH	7.8	7.8	6.7	6.8
Nitrogen (% wb)				
- total	0.351	0.402	0.379	0.360
- organic	0.264	0.324	0.207	0.193
- ammonia	0.087	0.078	0.172	0.167
Phosphorous (% wb)				
- P	0.117	0.132	0.067	0.065
- P_2O_5	0.268	0.302	0.153	0.149
Potassium (% wb)				
- K	0.261	0.310	0.202	0.191
- K_2O	0.313	0.372	0.242	0.229

Figures 16-18 show the change in concentration of DM, N_T, N_O, P and K over the test period including the days the cattle were not present in the barn. The aerobic and anaerobic curves were obtained from the means of the variables for Pits No. 1 and No. 2, and Pits No. 3 and No. 4 respectively. The difference between the concentration curves for N_T and N_O is N_{NH_3}.

5.4.1 Analysis of Variance Results - Percentage Concentrations.

Highly significant differences between the two forms of decomposition were found to exist for the concentrations of DM, N_O, N_{NH_3}, P and K (table 31). However, N_T concentrations were not significantly different between the aerobic and anaerobic treatments as shown in the table and by the relative closeness of the two curves in figure 17.

TABLES 31: ANALYSIS OF VARIANCE - WASTE NUTRIENTS (PERCENT) FOR AEROBIC AND ANAEROBIC TREATMENTS.

	Source of Variation	Degrees of Freedom	Mean Squares	F
(a) DM	Between Treatments	1	119.025	56.60**
	Within Treatments	38	2.103	
(b) N_T	Between Treatments	1	0.0005625	<1.00
	Within Treatments	38	0.0050139	
(c) N_O	Between Treatments	1	0.0894920	34.57**
	Within Treatments	38	0.0025886	
(d) N_{NH_3}	Between Treatments	1	0.0757770	50.94**
	Within Treatments	38	0.0014875	

Cont'd.

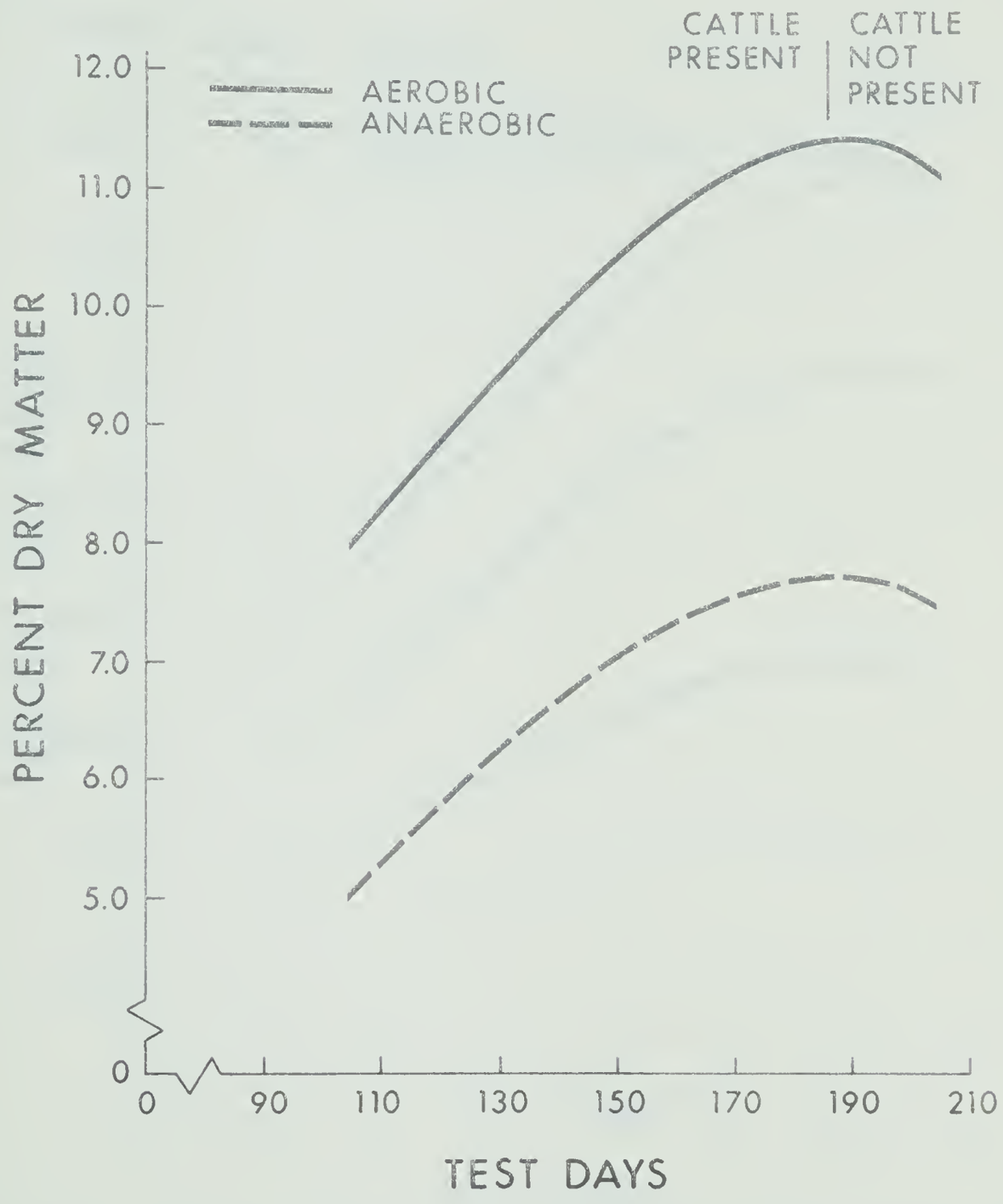


Figure 16: Graph illustrating the change in percentage DM over the test period for the aerobic and anaerobic treatments. Finished animals were removed from pens from day 143 to day 185, after which all pens were vacated.

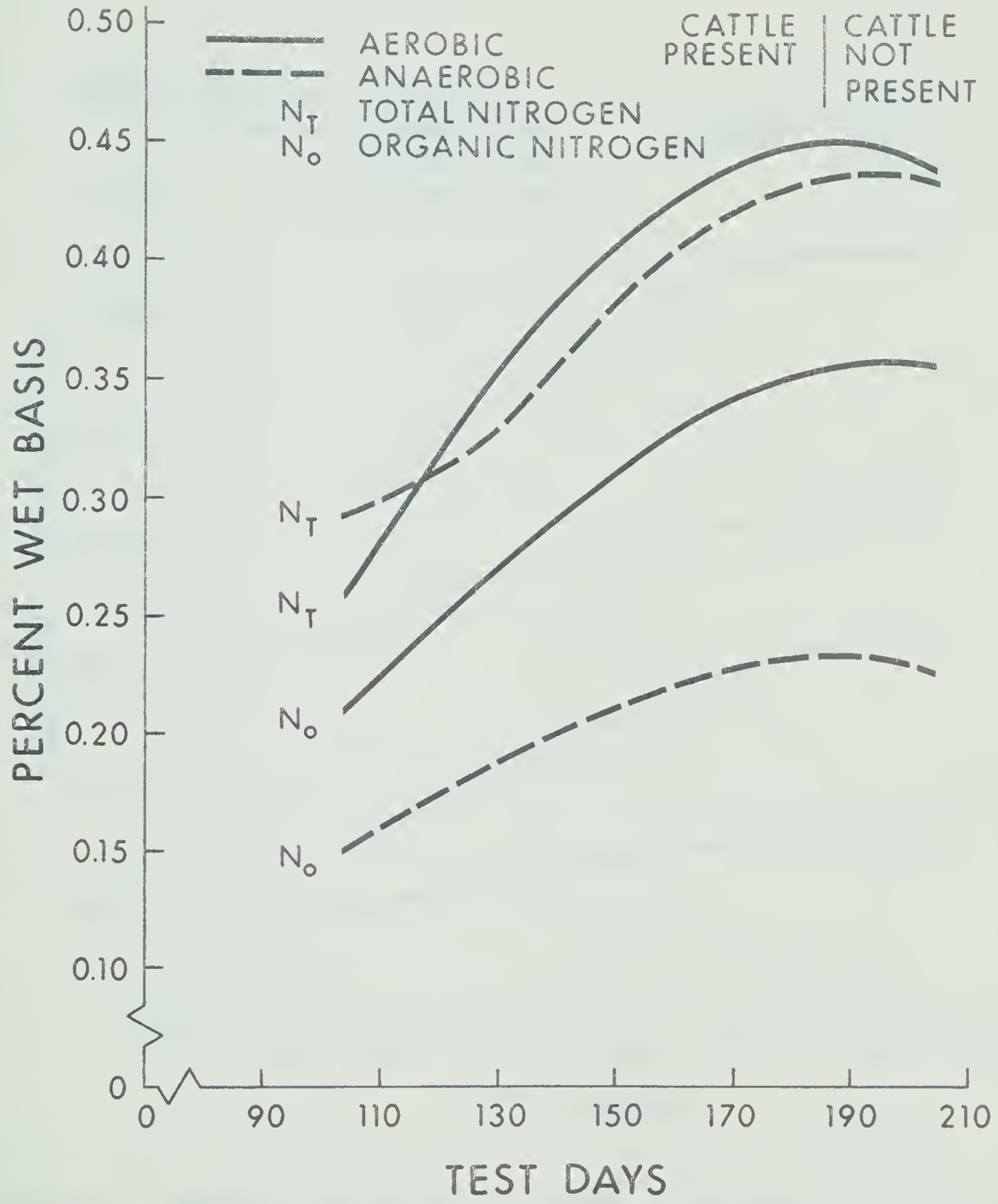


Figure 17: Graph illustrating the change in percentage N_T and N_O over the test period for the aerobic and anaerobic treatments. Finished animals were removed from pens from day 143 to day 185, after which all pens were vacated.

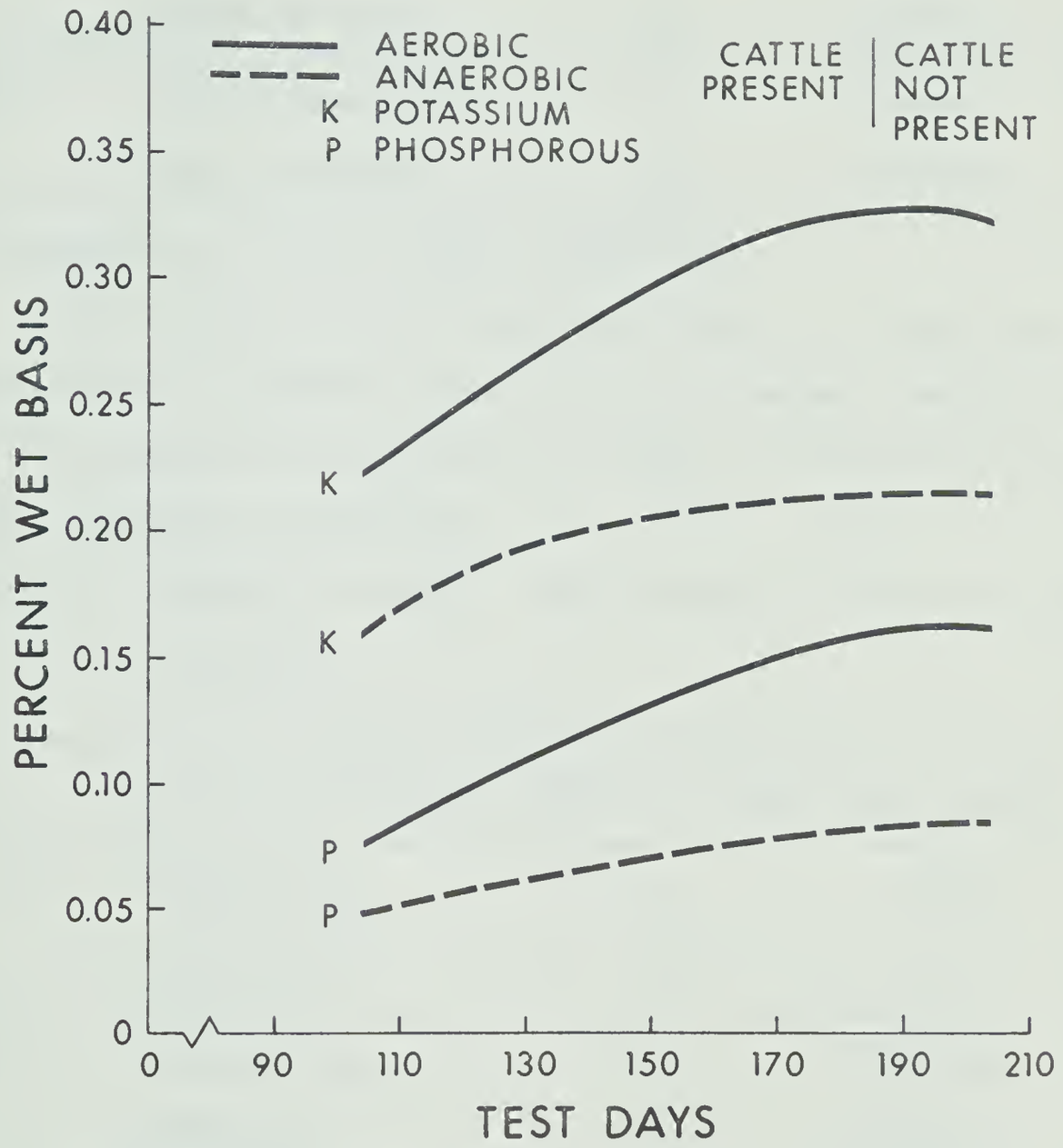


Figure 18: Graph illustrating the change in percentage P and K over the test period for the aerobic and anaerobic treatments. Finished animals were removed from pens from day 143 to day 185, after which all pens were vacated.



TABLE 31: (continued)

	Source of Variation	Degrees of Freedom	Mean Squares	F
(e) P	Between Treatments	1	0.0338770	45.97**
	Within Treatments	38	0.0007369	
(f) K	Between Treatments	1	0.0785880	47.28**
	Within Treatments	38	0.0016620	

** significant at the .01 level of probability.

The F-values in table 32 show that there was no significant concentration differences between the aerobic treatments except for N_O and K. The difference in concentration for these two variables was significant at the .05 level of probability.

TABLES 32: ANALYSIS OF VARIANCE - WASTE NUTRIENTS (PERCENT) FOR AEROBIC TREATMENTS.

	Source of Variation	Degrees of Freedom	Mean Squares	F
(a) DM	Between Pits	1	7.200	3.10
	Within Pits	18	2.325	
(b) N_T	Between Pits	1	0.0128520	2.11
	Within Pits	18	0.0061020	
(c) N_O	Between Pits	1	0.0181202	5.59*
	Within Pits	18	0.0032401	
(d) N_{NH_3}	Between Pits	1	0.0004512	<1.00
	Within Pits	18	0.0013830	

TABLES 32: (continued)

	Source of Variation	Degrees of Freedom	Mean Squares	F
(e) P	Between Pits	1	0.0010224	<1.00
	Within Pits	18	0.0012125	
(f) K	Between Pits	1	0.0120540	5.37*
	Within Pits	18	0.0022377	

* significant at the .05 level of probability.

Between the anaerobic treatments, no significant concentration differences were shown for any of the variables tested (table 33).

TABLE 33: ANALYSIS OF VARIANCE - WASTE NUTRIENTS (PERCENT) FOR ANAEROBIC TREATMENTS.

	Source of Variation	Degrees of Freedom	Mean Squares	F
(a) DM	Between Pits	1	1.352	<1.00
	Within Pits	18	1.641	
(b) N_T	Between Pits	1	0.0019012	<1.00
	Within Pits	18	0.0036634	
(c) N_O	Between Pits	1	0.0009800	<1.00
	Within Pits	18	0.0011636	
(d) N_{NH_3}	Between Pits	1	0.0001458	<1.00
	Within Pits	18	0.0017242	
(e) P	Between Pits	1	0.0000220	<1.00
	Within Pits	18	0.0002935	

TABLE 33: (continued)

	Source of Variation	Degrees of Freedom	Mean Squares	F
(f) K	Between Pits	1	0.0006498	1.15
	Within Pits	18	0.0005652	

5.4.2 Analysis of Variance Results - Quantities.

As previously stated in section 5.3.2, comparisons between wastes of widely differing dilutions may have limitations. Comparison between pits, based on the quantities of the variable in question, may be more appropriate.

The quantity, in pounds per pit, for each of the variables in section 5.4 were determined using the pit volume, specific gravity and the percentage variable concentration for each sampling day. The means of the values for each variable are shown in table 34.

TABLE 34: MEAN QUANTITIES OF WASTE NUTRIENTS PER PIT.

	Aerobic		Anaerobic	
Pit Number	1	2	3	4
Characteristic				
Dry Matter (lb)	5690	5930	5350	5020
Nitrogen (lb)				
- total	212	224	296	283
- organic	159	180	161	153
- ammonia	53	43	135	130

Cont'd.

TABLE 34: (continued)

Pit Number	Aerobic 1	2	Anaerobic 3	4
Phosphorous (lb)				
- P	71	73	53	52
- P_2O_5	162	167	121	119
Potassium (lb)				
- K	157	172	156	150
- K_2O	188	206	187	180

The analysis of variance in table 35 shows the results of the comparison between aerobic and anaerobic treatments. No significant difference was found between the two forms of decomposition for the variables, DM, N_O and K. However, for the variables, N_T, N_{NH_3} and P, highly significant differences were found.

TABLE 35: ANALYSIS OF VARIANCE - WASTE NUTRIENTS (LB/PIT) FOR AEROBIC AND ANAEROBIC TREATMENTS.

	Source of Variation	Degrees of Freedom	Mean Squares	F
(a) DM	Between Treatments	1	3,907,500	2.77
	Within Treatments	38	1,408,900	
(b) N_T	Between Treatments	1	51,624	13.65**
	Within Treatments	38	3,781	
(c) N_O	Between Treatments	1	1,664	1.23
	Within Treatments	38	1,352	

Cont'd.

TABLE 35: (continued)

	Source of Variation	Degrees of Freedom	Mean Squares	F
(d) N_{NH_3}	Between Treatments	1	71,700	61.81**
	Within Treatments	38	1,107	
(e) P	Between Treatments	1	3,725	10.92**
	Within Treatments	38	341	
(f) K	Between Treatments	1	1,369	1.68
	Within Treatments	38	816	

** significant at the .01 level of probability.

Tables 36 and 37 give the analysis of variance results for the comparison of pits within the aerobic and anaerobic forms of decomposition respectively.

TABLE 36: ANALYSIS OF VARIANCE - WASTE NUTRIENTS (LB/PIT) FOR AEROBIC TREATMENTS.

	Source of Variation	Degrees of Freedom	Mean Squares	F
(a) DM	Between Pits	1	286,800	<1.00
	Within Pits	18	585,080	
(b) N_T	Between Pits	1	708	<1.00
	Within Pits	18	1875	
(c) N_O	Between Pits	1	2311	2.70
	Within Pits	18	856	

TABLE 36: (continued)

	Source of Variation	Degrees of Freedom	Mean Squares	F
(d) N_{NH_3}	Between Pits	1	470	<1.00
	Within Pits	18	499.	
(e) P	Between Pits	1	24.1	<1.00
	Within Pits	18	358.4	
(f) K	Between Pits	1	1,217	2.01
	Within Pits	18	606	

For each of the variables in question, no significant difference in the amount per pit was observed between the two aerobic pits. Similar results are shown for anaerobic pits, No. 3 and No. 4.

TABLE 37: ANALYSIS OF VARIANCE - WASTE NUTRIENTS (LB/PIT) FOR ANAEROBIC TREATMENTS.

	Source of Variation	Degrees of Freedom	Mean Squares	F
(a) DM	Between Pits	1	536,280	<1.00
	Within Pits	18	2,343,500	
(b) N_T	Between Pits	1	845	<1.00
	Within Pits	18	6,022	
(c) N_O	Between Pits	1	344	<1.00
	Within Pits	18	1,851	

TABLE 37: (continued)

	Source of Variation	Degrees of Freedom	Mean Squares	F
(d) N_{NH_3}	Between Pits	1	110	<1.00
	Within Pits	18	1,807	
(e) P	Between Pits	1	5.3	<1.00
	Within Pits	18	360.0	
(f) K	Between Pits	1	180	<1.00
	Within Pits	18	1,039	

5.4.3 Multiple Regression - Estimation of Waste Nutrients.

Daily livestock feed records and analyses of feedstuffs are being used by an increasing number of feedlot operators and farmers each year. Liquid manure storage, treatment and handling, especially in dairy, swine and poultry operations, also is becoming more widespread. These factors should make it possible to determine some type of equation to estimate the plant nutrient value of the livestock wastes.

The following multiple regressions were determined using the feed records of the beef feeder cattle used in this project (57,58) and the data obtained from the tests conducted by the SFT Laboratory. The ranges for the equations can be determined from the data in Appendix 9.

Several independent variables and their interactions were tried in the stepwise multiple regression program (20). However, only the variables defined as follows finally were used:

(a) Pit dry matter (DM_p) - the amount of dry matter, in pounds, present in the pit at the time of sampling for this variable.

(b) Time (T) - the total collection and/or storage time of the liquid manure to the time of sampling. This includes the time that the pits were receiving animal wastes (collection) plus the time they were not (storage).

(c) (i) Feed dry matter (DM_f),

(ii) Feed nitrogen (N_f),

(iii) Feed phosphorous (P_f), and

(iv) Feed potassium (K_f)

- the cumulative sum for each of the feed variables listed which was fed to the cattle over time T.

Since the analyses, due to the nature of the project, could not prove relationships between these independent variables and the dependent variables, N_T, N_O, P and K, significant simple correlations at the .01 probability level, were found to exist between the two types of variables.

The general model considered for the multiple regressions had the following form:

$$Y = A + B_1X_1 + B_2X_2 \ldots\ldots + B_iX_i$$

where Y = dependent variable (N_T, N_O, P or K in lb/pit)

$X_1 \ldots X_i$ = independent variables (DMp, T, DM_f, N_f, P_f, K_f or their interactions),

A = intercept,

$B_1 \ldots B_i$ = multiple partial correlation coefficients, and

i = number of independent variables (or interactions) used.

5.4.3.1 Multiple Regression - Estimation of Nitrogen Content.

For the nitrogen multiple regression, the following dependent variables were used:

(a) total nitrogen (N_T) in pounds, present in a pit for

(i) an aerobic and

(ii) an anaerobic collection - storage liquid manure system; and

(b) organic nitrogen (N_0), in pounds, present in a liquid manure system (aerobic or anaerobic).

The multiple regression for aerobic total nitrogen is shown in table 38. The multiple correlation coefficient of 0.932 indicated a very good relationship between the dependent and the chosen independent variables.

The cumulative proportion of the total sum of squares accounted for by the independent variables was 0.882. The significance of this reduction in sum of squares due to regression is indicated by the highly significant F-values as shown by the regression's analysis of variance.

TABLE 38: REGRESSION ANALYSIS FOR THE ESTIMATION OF TOTAL NITROGEN - AEROBIC.

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Squares	F
Attributable to Regression	3	30,395	10,132	39.93**
Deviation from Regression	16	4,059	254	
Total	19	34,454		

Regression Equation:

$$N_T = -17.7 + 0.499\ N_f + 0.016\ DMp - 0.830T$$

Cont'd.

TABLE 38: (continued)

Multiple Correlation Coefficient = 0.932

Cumulative Proportion of Sum of Squares Reduced = 0.882

Standard Error of the Estimate = 16.8 lb.

** significant at the .01 level of probability.

Table 39 gives the results of the multiple regression for anaerobic total nitrogen.

TABLE 39: REGRESSION ANALYSIS FOR THE ESTIMATION OF TOTAL NITROGEN - ANAEROBIC.

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Squares	F
Attributable to Regression	3	98,018	32,673	46.57**
Deviation from Regression	16	11,225	702	

Regression Equation:

$$N_T = 11.6 + 0.00011\ N_f^2 + 0.0121\ DMp + 1.21T$$

Multiple Correlation Coefficient = 0.941

Cumulative Proportion of Sum of Squares Reduced = 0.897

Standard Error of the Estimate = 28.0 lb.

** significant at the .01 level of probability.

Since the amounts of organic nitrogen present in the aerobic and anaerobic pits were not significantly different (table 35), the data for both systems were combined to determine a multiple regression equation for the estimation of organic nitrogen (table 40).

TABLE 40: REGRESSION ANALYSIS FOR THE ESTIMATION OF ORGANIC NITROGEN.

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F
Attributable to Regression	2	48,701	24,350	207.35**
Deviation from Regression	37	4,345	117	
Total	39	53,046		

Regression Equation:

$$N_0 = -2.67 + 0.205\ DMp + 0.356T$$

Multiple Correlation Coefficient = 0.957

Cumulative Proportion of Sum of Squares Reduced = 0.918

Standard Error of Estimate = 11.0 lb.

** significant at the .01 level of probability.

5.4.3.2 Multiple Regression - Estimation of Phosphorous Content.

The phosphorous content (P), in pounds, present in (i) an aerobic and (ii) an anaerobic liquid manure system are used as the dependent variables in the following two regressions.

The regression analysis for aerobic phosphorous content is given in table 41. The results given for the multiple correlation coefficient and the proportion of sum of squares reduced indicate a very good relationship between the chosen independent and the dependent variables.

TABLE 41: REGRESSION ANALYSIS FOR THE ESTIMATION OF PHOSPHOROUS - AEROBIC.

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Squares	F
Attributable to Regression	2	6,224	3,112	220.71**
Deviation from Regression	17	240	14	

Regression Equation:

$$P = 1.59 + 0.0043\ P_f^2 + 0.0065\ DMp$$

Multiple Correlation Coefficient = 0.980

Cumulative Proportion of Sum of Squares Reduced = 0.963

Standard Error of the Estimate = 3.86 lb.

** significant at the .01 level of probability.

Table 42 gives the regression analysis for anaerobic phosphorous content. The results shown in the table indicate similar relationships as those found for the aerobic phosphorous content.

TABLE 42: REGRESSION ANALYSIS FOR THE ESTIMATION OF PHOSPHOROUS - ANAEROBIC.

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Squares	F
Attributable to Regression	2	6,158	3,079	160.34**
Deviation from Regression	17	326	19	
Total	19	6,465		

Cont'd.

TABLE 42: (continued)

Regression Equation:

$$P = -17.3 + 0.324P_f + 0.0081\ DMp$$

Multiple Correlation Coefficient = 0.973

Cumulative Proportion of Sum of Squares Reduced = 0.950

Standard Error of the Estimate = 4.50 lb.

** significant at the .01 level of probability.

5.4.3.3 Multiple Regression - Estimate of Potassium Content.

Although the potassium content of the feeds fed during this project was not determined by laboratory analysis, it was estimated using the average values for similar feeds from standard references (table 5).

The dependent variables used in this analysis are the amounts of potassium (K), in pounds, for (i) an aerobic and (ii) an anaerobic liquid manure system. Table 35 shows that the amount of K was not significantly different between the aerobic and anaerobic pits. However, the regression analysis for the individual treatments gave better results than those obtained when all the data was combined.

The regression analysis results in table 43 are for the estimation of K for an aerobic system.

TABLE 43: REGRESSION ANALYSIS FOR THE ESTIMATION OF POTASSIUM - AEROBIC.

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Squares	F
Attributable to Regression	3	11,047	3,682	54.21**
Deviation from Regression	16	1,087	68	
Total	19	12,134		

Cont'd.

TABLE 43: (continued)

Regression Equation:

$$K = -7.60 + 0.0285\ DMp - 0.0230\ K_f + 0.00083\ DM_f$$

Multiple Correlation Coefficient = 0.949

Cumulative Proportion of Sum of Squares Reduced = 0.910

Standard Error of the Estimate = 8.71 lb.

** significant at the .01 level of probability.

Table 44 gives the results of the regression analysis for the estimation of the amount of K present in an anaerobic treatment pit. The table shows that the statistical parameters obtained for the aerobic system were slightly better than those obtained for the anaerobic treatment.

TABLE 44: REGRESSION ANALYSIS FOR THE ESTIMATION OF POTASSIUM - ANAEROBIC.

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Squares	F
Attributable to Regression	2	15,562	7,781	39.93**
Deviation from Regression	17	3,312	195	
Total	19	18,874		

Regression Equation:

$$K = -0.72 + 0.0105\ DMp + 0.204\ K_f$$

Multiple Correlation Coefficient = 0.903

Cumulative Proportion of Sum of Squares Reduced = 0.825

Standard Error of the Estimate = 14.3 lb.

** significant at the .01 level of probability.

5.5 Estimated Reductions of Total Solids and Biochemical Oxygen Demand.

Since the fresh wastes of the beef cattle were not analyzed, only estimations of the percentage reductions for TS and BOD_5 can be made. The records for the livestock weights and beef animal waste properties, as found in the review of literature (sections 2.1.1 and 2.6.1), were used for the estimations. The daily waste properties that were used are:

(1) animal waste production - 6 percent of body weight,

(2) total solids - 15 percent of total waste production, and

(3) BOD_5 - 0.19 pounds per pound total solids.

The percent reduction of TS from commencement of the project (day 0) to day 184, one day prior to the animals being removed from the building, and to day 209 when the last set of samples for TS were taken, are shown in table 45. The table gives the estimated total solids added to the pit, the total solids remaining on the test day and the estimated reduction of TS to that day. Also shown is the actual reduction of TS between days 184 and 209 for the four pits.

Table 46 gives the estimated reductions for BOD_5, from day 0 to the test day 184, about the time that the cattle were removed, and day 203, the last day of sampling for BOD_5.

TABLE 45: ESTIMATED PERCENT REDUCTION OF TOTAL SOLIDS.

	Reduction to day 184			Reduction to day 209			Between day 184 and day 209
	Estimated TS added (lb)	Actual TS remaining (lb)	TS reduction %	Estimated TS added (lb)	Actual TS remaining (lb)	TS reduction %	TS reduction %
Aerobic							
Pit 1	11,100	6,420	42	11,300	6,160	46	4.0
Pit 2	11,100	6,920	37	11,300	6,060	46	12.4
Anaerobic							
Pit 3	11,300	7,000	38	11,500	6,850	40	2.1
Pit 4	11,300	7,570	33	11,500	6,360	45	16.0

TABLE 46: ESTIMATED PERCENT REDUCTION OF BOD_5

	Reduction to day 184			Reduction to day 209		
	Estimated BOD_5 added (lb)	Actual BOD_5 remaining (lb)	BOD_5 reduction %	Estimated BOD_5 added (lb)	Actual BOD_5 remaining (lb)	BOD_5 reduction %
Aerobic						
Pit 1	2,110	530	75	2,150	430	80
Pit 2	2,110	610	71	2,150	640	70
Anaerobic						
Pit 3	2,150	1,880	13	2,180	1,970	10
Pit 4	2,150	1,780	17	2,180	1,850	15

6. DISCUSSION

The purpose of the project was to determine the effects of treating beef cattle wastes under actual conditions. Two forms of waste decomposition were compared in this study, namely, aerobic and anaerobic.

The conditions for anaerobic decomposition were achieved by using two similar pits, No. 3 and No. 4, to collect and store the wastes of feeder cattle. Aerobic decomposition was accomplished using the principle of the oxidation ditch. Since two levels of aeration were to be compared, Pit No. 1 was supplied with one rotor for slurry aeration and agitation while two rotors were used in Pit No. 2.

As a result of the nature of the project, there were obvious limitations from a statistical viewpoint with regard to control of variables. However, the analysis of the data obtained several significant results.

6.1 Aerobic versus Anaerobic Decomposition.

Highly significant differences were found between the two forms of decomposition, for the concentrations of the waste characteristics. However, no significant differences, except for BOD_5, were observed when the effect of dilution was removed.

The pollution potential, as measured by BOD_5, of the beef cattle wastes treated anaerobically, was three to four times greater than that of the aerobic treatments. After 185 days of loading plus 18 days of additional treatment, the aerobic oxidation ditches had an estimated BOD_5 reduction of 70-80 percent compared to a reduction of 10-20 percent for the anaerobic treatments.

Compared with other studies, both aerobic and anaerobic, the

concentrations of BOD_5 obtained in this project were similar to some but differed widely from others. Comparison between studies, on the basis of concentration or even dry matter, is difficult due to the lack of reported information on factors such as the extent of dilution, pit volumes and animal size or loading in many such studies. Some standard basis for the presentation of results relating to studies on waste strength such as BOD_5 per animal-day, would appear very desirable if valid comparisons of pollution potential under different experimental and practical conditions are to be attempted.

For the waste nutrient samples, significant differences in percentage concentrations between the aerobic and anaerobic systems were found. An exception to this was the concentration of total nitrogen which was not significantly different. Removing the effect of dilution, the analyses showed that the only differences between the two systems were for total and ammonia nitrogen, and phosphorous.

The ammonia nitrogen in the anaerobic pits was two and one half to three times the quantity present in the oxidation ditches. The differences in ammonia nitrogen quantity between systems most probably was due to the agitation of the slurry in the oxidation ditches which would facilitate the escape of ammonia into the atmosphere. Therefore, since no significant differences were observed between the quantities of organic nitrogen, the higher total nitrogen found in the anaerobic treatments was a result of the higher ammonia nitrogen.

Since the pits were only sampled to within one foot of the pit floors, the larger solids settling out in the unagitated anaerobic pits would probably account for the differences in the quantity of phosphorous present in the two systems.

Losses from the pits, of P and K, are not possible except by solids removal, and therefore, the respective quantities of each would be expected to be the same for both systems. Since the average differences between the two systems were about 20 pounds for P and 10 pounds for K, it would seem that some solids had settled out. Although not significantly different, the anaerobic pits had about 11 percent less dry matter, on the average, than the oxidation ditches. However, Muehling (51) cites Miner as stating that the anaerobic process was able to decompose more organic matter per unit volume than its aerobic counterpart.

The values for pH found in this study were similar to those found by other researchers for both systems. However, the differences between the aerobic pH data (tables 20 and 30) as determined by SFT Laboratory and the author probably were due to the anaerobic activity caused by:

(1) longer periods of non-aeration, due to rotor failure, prior to obtaining the SFTL samples, and/or

(2) cold overnight storage prior to the analyses of some of the SFTL samples.

A third reason may be a consequence of operator procedure but the similarity between anaerobic pH would tend to discount this possibility.

6.2 Differences Between Pits Within a Decomposition System.

No significant differences were found between the two anaerobic pits, No. 3 and No. 4, with or without the effect of dilution since throughout the project, the pits had similar volumes at time of sampling.

Between the oxidation ditches, Pits No. 1 and No. 2, no differences were observed after removing the effect of dilution. However, the two pits had significantly different concentrations for total solids, volatile

total solids, organic nitrogen and potassium. These differences would be largely due to the changes in the volume of liquid in the pits caused by varying rates of evaporation induced by rotor operation.

6.3 BOD_5 Regression.

The results of two fairly rapid and simple tests, total solids and oxygen demand index, were used to determine regression equations to estimate BOD_5. The accuracy of the equations found in this project may be in question since the BOD_5 values used in the regression determinations had a mean BOD_5 temperature of $24.0^{\circ}C$.

Using the data obtained, the sum of squares accounted for by the regressions were 70.9% and 69.6% for the aerobic and anaerobic equations respectively. These percentages and the significant multiple correlations obtained indicated that such equations may be determined using data from a more controlled experiment.

Although many livestock waste researchers have compared BOD_5 to COD, no reference was found in the literature review where the ODI test was used. However, Simpson (60), in regard to municipal wastes, stated that each waste should be classed separately since no single ODI to BOD ratio could be applied to all wastes due to their complex nature. Therefore, the regressions for BOD_5 determined in this study must be further evaluated to determine their general applicability to other livestock wastes, including those from beef cattle maintained under conditions of environment and feeding different from those prevailing during this project.

6.4 Regressions for Waste Nutrients

Using daily feed records, feed analysis and the tests on liquid manure samples, for specific gravity and dry matter content, regressions

were determined for the amounts of several fertilizer nutrients present in the slurry pits. The high multiple correlations and the large percentage of sum of squares reduced, as found in this study, indicated that fairly accurate regressions may be possible.

Although good statistiacl results were obtained for the total nitrogen, the quantity of ammonia present in aerobic or anaerobic pits may change rapidly when the pits are agitated prior to waste removal or after disposal on land. As a result, the regression analyses of total nitrogen, especially the one for an anaerobic system, may be questioned. A more accurate estimation of the nitrogen being applied to the soil would be the equation for organic nitrogen. As used here, the term organic nitrogen, refers to all nitrogen not lost during drying (section 4.3.1). Although this nitrogen is largely organic, some small quantities of nitrates and nitrites may be present (46,72).

6.5 Seeding and Lag Periods.

During the early stages of the study, seeding of the BOD samples was attempted (Appendix VI). The lag periods, obtained from the slope method of k and L determination, show that seeding had no effect on decreasing the BOD lag. The seeding of animal wastes undergoing treatment, aerobic or anaerobic, may not be required since a large organism population is probably present. Fresh and/or freeze-stored wastes, which did respond to seeding (67), may have a small or weak population and, therefore, would benefit from seeding.

6.6 Observations and Problems of Rotor and Ditch Operations.

Rotor breakdowns posed a problem throughout the entire project. Stoppages, due to the failure of bearings and chains, occurred several times. Occasionally, repair operations were held up when replacement

parts were not available.

Bearing failure was apparently the result of liquid and solids getting into the bearing. Wear, corrosion and rust played a large part in chain and shaft failures. Large, matted masses of hair were usually found wrapped around both shafts. The part this material played in rotor breakdowns is not known.

Covers and seals were used in an attempt to protect the bearings but with little success. Towards the end of the project, hardwood blocks of oak, soaked in linseed oil, replaced the lower bearings with appreciably better results.

The overall design of the rotors assembly may have been a factor in the breakdown. Bearing life may have been reduced due to the load caused by the twisting action of the lower end of the assembly and the shock load created as each row of teeth entered the slurry. By placing the teeth in a spiral row and by designing the assembly so that the lower end is solid, the length of time between breakdowns may be increased.

In other trials (46,49,51), the oxidation ditch rapidly became anaerobic without aeration. Similar observations were noted in this study. Another problem that occurred was the very slow movement of slurry if the amount of dilution became too low. Increasing the depth, by about one half inch, with a water spray increased the pit movement. A water spray usually cleared up the foaming that occurred when a rotor was restarted after a breakdown within a few hours. The amount of foaming observed in this study did not approach the seriousness of that found in other studies (30,46,51,72,74).

Although both systems were loaded nearly equally with wastes, the difference in depths (Appendix V) showed a greater amount of water loss

through evaporation from the ditches, even with the additional water added for rotor assembly cleaning, and for foaming and dilution problems. The ditches also showed a greater change in slurry temperature (Appendix V). Both of these differences are assumed to be the result of the agitating action of the rotors which increases the liquid-air surface.

Odors were stronger in the anaerobic than the aerobic samples. Also, upon entering the aerobic pits after a breakdown period of several days, stronger odors were noticed than those after a period of a few hours.

6.7 Value of Field Research for Livestock Waste Treatments.

The use of field research in livestock waste management studies has disadvantages compared with laboratory research which provides cleaner surroundings and superior opportunities for experimental control. In field research, conditions usually are similar to those found in actual practice.

In the laboratory, fresh wastes, collected directly from the animal, are often used for experiments. These are added to digestors, aerobic or anaerobic, which normally are operated at fairly constant temperatures. As experienced in this project, animal spillage of feed and water, intentional water additions, evaporation,mechanical breakdowns, and temperature changes are continuously changing the environment in which the organisms of decomposition inhabit. These continuously changing conditions can not be simulated with any great accuracy in a laboratory.

While laboratory research is very necessary in developing new ideas and methods of treating and handling livestock wastes, the experience gained in this project indicates that field research is essential to evaluate laboratory findings under practical conditons and to collaborate, modify or reject these findings on this basis.

7. CONCLUSIONS

The following conclusions are drawn from this project:

1. Significant differences in concentration existed between the aerobic and anaerobic forms of decomposition for five-day biochemical oxygen demand, oxygen demand index, total solids, volatile total solids, dry matter, phosphorous, potassium, and organic and ammonia nitrogen while no significant differences existed for total nitrogen concentration.
2. When the effect of dilution was removed, significant differences between the two forms of decomposition were found only for five-day biochemical oxygen demand, total and ammonia nitrogen, and phosphorous.
3. The pollution potential of anaerobic treatments, based on five-day biochemical oxygen demand, was three to four times that of the aerobic treatments. The mean five-day biochemical oxygen demand for the aerobic and anaerobic treatments were 380 pounds (6740 mg/1) and 1300 pounds (17,200 mg/1) respectively. Estimated reduction was 70-80 percent for the aerobic system and 10-20 percent for the anaerobic.
4. Significant differences in the concentrations of the variables, total solids, volatile total solids, organic nitrogen and potassium, were noted between the two levels of aeration.
5. No significant differences were observed between the two levels of aeration when compared on a dry matter basis (no dilution effect. The use of two rotors had no significant effects compared with the use of one rotor.

6. Regression analyses indicated that using the tests for oxygen demand index and total solids as independent variables, an estimate of BOD_5 may be determined.

7. Regression analyses indicated that the quantity of plant nutrients in a liquid manure pit may be estimated using daily livestock feed records, feed analysis and the quantity of dry matter in the liquid manure.

8. The biochemical oxygen demand constants, for growth rate (k) and for ultimate biochemical oxygen demand (L), for the anaerobic treatment were significantly greater than those determined for the aerobic conditions. The mean values for k were 0.132 and 0.236 $days^{-1}$, respectively, for the aerobic and anaerobic treatments. The respective mean values of L were 10,100 and 18,700 mg/l.

8. SUGGESTIONS FOR FURTHER STUDY

The analytical experience gained from this project would suggest the need for some modification or improvement of tests used to determine the strength characteristics of animal wastes. In particular, any further studies might provide answers to the following questions:

1. Could the oxygen demand index test be modified, possibly by increasing reagent strength, to reduce the amount of dilution required for samples of the highly concentrated wastes characteristic of animal wastes?
2. To reduce the dilution factors for highly concentrated wastes, is it possible to increase the length of the reading scale of the Hach BOD apparatus without affecting its operation or reliability?

The regressions developed in this study have appreciable practical significance from the viewpoint of field disposal of animal wastes. Further studies are required to answer the following questions:

1. Will the regressions hold for beef cattle wastes for other conditions of environment and feeding?
2. Can similar equations be developed for the wastes of other livestock?

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10. APPENDICES

APPENDIX I

DATA FROM SOILS AND FEED TESTING LABORATORY

The data presented in the following tables are the results of the tests conducted at the Alberta Soils and Feed Testing Laboratory, Edmonton. The first group of tables show dry matter content (DM), specific gravity (SG) and pH while the second set of tables show phosphorus (P) and potassium (K) content on both wet (wb) and dry (db) basis for each of the four pits. The final set of tables give the nitrogen content of the waste in each pit as follows:

(a) N_{DM} - total Kjehldahl nitrogen of dried waste sample on dry basis;

(b) $N_O - N_{DM}$ converted to wet basis (largely organic nitrogen);

(c) N_T - total Kjehldahl nitrogen of liquid waste sample on wet basis; and

(d) N_{NH_3} - ammonia nitrogen (wet basis) lost during drying ($= N_T - N_O$).

	Test day	DM %	SG	pH
Pit 1	103	8.2	1.017	7.8
	110	7.7	10.09	7.7
	117	8.1	1.028	7.7
	131	9.2	1.028	7.6
	138	9.4	1.024	7.4
	152	9.4	1.031	6.6
	166	10.5	1.030	7.9
	180	10.9	1.024	8.5
	194	10.5	1.040	8.5
	205	10.6	1.026	8.1
Pit 2	103	8.1	1.020	8.0
	110	8.3	1.029	7.7
	117	8.7	1.036	8.0
	131	10.4	1.020	7.9
	138	10.8	1.029	7.9
	152	11.2	1.027	7.7
	166	11.7	1.025	7.3
	180	13.8	1.021	7.9
	194	11.9	1.035	8.2
	205	11.6	1.020	7.7

	Test day	DM %	SG	pH
Pit 3	103	5.8	1.020	6.7
	110	4.9	1.008	6.6
	117	5.9	1.004	6.7
	131	6.9	1.015	6.7
	138	7.2	1.010	6.8
	152	5.4	1.021	6.7
	166	8.5	1.019	6.7
	180	8.4	1.016	6.8
	194	7.6	1.023	6.5
	205	8.0	1.013	6.8
Pit 4	103	5.9	1.013	6.6
	110	4.7	1.016	6.7
	117	5.3	1.009	6.7
	131	5.8	1.016	6.6
	138	5.1	1.012	6.9
	152	6.0	1.020	7.5
	166	8.4	1.021	6.7
	180	8.2	1.012	6.7
	194	6.9	1.024	6.5
	205	7.1	1.023	6.7

	Test day	Phosphorus		Potassium	
		% db	% wb	% db	%wb
Pit 1	103	0.97	0.080	2.58	0.213
	110	0.96	0.078	2.55	0.209
	117	1.03	0.090	2.50	0.217
	131	0.99	0.096	2.55	0.247
	138	1.11	0.110	2.66	0.264
	152	1.27	0.126	2.44	0.242
	166	1.27	0.148	2.41	0.282
	180	1.24	0.143	2.88	0.334
	194	1.30	0.144	2.65	0.294
	205	1.41	0.158	2.72	0.304
Pit 2	103	0.99	0.081	2.88	0.234
	110	0.96	0.085	2.80	0.249
	117	0.99	0.092	2.78	0.258
	131	0.99	0.109	2.62	0.288
	138	1.06	0.121	2.88	0.328
	152	1.23	0.145	2.57	0.303
	166	1.23	0.160	2.66	0.345
	180	1.24	0.182	2.65	0.390
	194	1.30	0.163	2.78	0.348
	205	1.39	0.178	2.77	0.354

	Test day	Phosphorus		Potassium	
		% db	% wb	% db	% wb
Pit 3	103	0.83	0.048	3.00	0.175
	110	0.81	0.044	3.50	0.189
	117	0.83	0.054	3.10	0.202
	131	0.81	0.058	2.91	0.210
	138	0.80	0.061	2.88	0.219
	152	1.11	0.063	2.66	0.150
	166	0.95	0.090	2.30	0.218
	180	0.89	0.080	2.38	0.213
	194	1.04	0.084	2.88	0.232
	205	1.08	0.091	2.55	0.214
Pit 4	103	0.78	0.050	2.13	0.136
	110	0.83	0.043	3.62	0.188
	117	0.90	0.052	3.22	0.186
	131	0.99	0.061	3.20	0.195
	138	0.94	0.051	3.45	0.186
	152	1.08	0.068	3.07	0.193
	166	1.02	0.096	2.21	0.210
	180	0.94	0.082	2.45	0.215
	194	1.02	0.074	3.00	0.217
	205	1.00	0.075	2.43	0.182

	Test day	N_{DM} % db	N_O % wb	N_T % wb	N_{NH_3} %wb
Pit 1	103	2.58	0.213	0.227	0.014
	110	2.44	0.200	0.258	0.058
	117	2.50	0.218	0.274	0.056
	131	2.44	0.237	0.302	0.065
	138	2.59	0.257	0.335	0.078
	152	2.71	0.269	0.382	0.113
	166	2.75	0.322	0.426	0.104
	180	2.63	0.305	0.474	0.169
	194	2.46	0.273	0.416	0.143
	205	3.11	0.348	0.420	0.072
Pit 2	103	2.98	0.242	0.285	0.043
	110	2.75	0.245	0.312	0.067
	117	2.67	0.248	0.333	0.085
	131	2.78	0.306	0.365	0.059
	138	2.83	0.323	0.416	0.093
	152	2.84	0.335	0.466	0.131
	166	2.83	0.367	0.448	0.081
	180	2.79	0.411	0.475	0.064
	194	2.90	0.363	0.464	0.101
	205	3.16	0.404	0.457	0.053

	Test day	N_{DM} % db	N_O % wb	N_T % wb	N_{NH_3} %wb
Pit 3	103	2.80	0.163	0.300	0.137
	110	3.09	0.167	0.298	0.131
	117	2.82	0.184	0.337	0.153
	131	2.77	0.200	0.336	0.136
	138	2.91	0.221	0.334	0.113
	152	3.26	0.184	0.423	0.239
	166	2.59	0.246	0.441	0.195
	180	2.39	0.214	0.416	0.202
	194	2.95	0.237	0.442	0.205
	205	2.98	0.251	0.463	0.211
Pit 4	103	2.52	0.160	0.377	0.217
	110	2.76	0.144	0.290	0.146
	117	2.70	0.156	0.312	0.156
	131	3.02	0.184	0.302	0.118
	138	3.29	0.178	0.303	0.125
	152	3.03	0.190	0.359	0.169
	166	2.70	0.256	0.428	0.172
	180	2.69	0.235	0.362	0.127
	194	2.86	0.206	0.415	0.209
	205	2.91	0.208	0.447	0.229

APPENDIX II

DATA: OXYGEN DEMAND INDEX, TOTAL SOLIDS, VOLATILE TOTAL SOLIDS AND pH.

The data obtained from tests for oxygen demand index (ODI), total solids (TS), volatile total solids (VTS) and pH over the test period are shown on the following pages. The following superscripts are used in the data summary:

(a) mean of six samples (Section 4.3.2.4),

(b) no data obtained, and

(c) trial run - mean of only 3 samples.

Pit 1

Test day	ODI[a] mg/l	TS mg/l	VTS mg/l	pH
79	——[b]	——[b]	——[b]	7.3
86	——[b]	62000	48000	7.1
94	——[b]	——[b]	——[b]	7.0
100	10700[c]	72000	54000	7.6
107	7200	78000	58500	8.0
114	9100	83000	60500	8.0
121	10300	89000	62000	8.4
127	11800	95500	68500	8.4
133	9300	98500	69500	8.2
142	10000	134000	90500	8.3
149	15500	102000	74000	8.2
156	13700	104500	72500	8.4
163	15000	105000	72000	8.4
170	15000	107500	78500	8.4
177	17800	108000	74000	8.3
184	18500	105500	72000	7.2
191	21400	103500	73000	8.2
197	18400	104000	69500	8.2
203	20300	104500	69000	8.2
209	22200	107000	73500	8.4

Pit 2

Test day	ODI[a] mg/l	TS mg/l	VTS mg/l	pH
79	——[b]	——[b]	——[b]	8.2
86	——[b]	67000	53500	8.0
94	——[b]	——[b]	——[b]	8.1
100	11200[c]	78000	57500	8.2
107	7200	85500	63000	8.2
114	11300	91000	66500	8.2
121	12600	97500	70500	8.5
127	13300	104500	75500	8.6
133	13300	108500	75500	8.5
142	13200	125500	86500	8.2
149	18400	115000	81000	8.4
156	14200	118500	82500	8.2
163	17900	116000	82000	8.3
170	14200	116500	84500	8.4
177	20300	121000	85000	8.2
184	20000	131000	92000	8.3
191	23800	139500	102500	8.3
197	22000	119000	80500	8.2
203	20200	114500	77000	8.2
209	23100	119000	80500	8.5

Pit 3

Test day	ODI[a] mg/l	TS mg/l	VTS mg/l	pH
79	—[b]	—[b]	—[b]	6.8
86	—[b]	42500	34500	6.9
94	—[b]	—[b]	—[b]	6.6
100	16800[c]	60000	44500	6.6
107	5400	66000	51500	6.6
114	7300	47500	35500	6.6
121	8800	53000	39500	7.0
127	8800	62500	46500	7.0
133	10700	86000	62000	6.8
142	10600	86000	58000	6.8
149	13400	77500	58000	6.7
156	12700	80000	57500	6.8
163	12700	78000	56500	6.8
170	10600	76000	55500	6.8
177	13000	86000	63000	6.8
184	15200	81000	57500	6.8
191	20300	73000	54500	6.8
197	16400	85500	61000	6.6
203	16200	82000	59500	6.7
209	16200	82500	59000	6.7

Pit 4

Test day	ODI[a] mg/l	TS mg/l	VTS mg/l	pH
79	—[b]	—[b]	—[b]	6.9
86	—[b]	38000	30000	6.9
94	—[b]	—[b]	—[b]	6.7
100	10600[c]	42500	32500	6.6
107	5800	59500	46000	6.6
114	8200	51500	38000	6.6
121	7600	50000	35500	7.0
127	9000	62000	45000	7.0
133	8800	73000	55500	6.9
142	10400	97000	70500	6.8
149	11900	58500	42500	6.8
156	12500	61000	45500	6.8
163	12300	68500	52000	6.8
170	12300	75500	56500	6.7
177	11400	61500	45500	6.8
184	14800	85500	62500	6.7
191	19300	70500	53000	6.7
197	16600	72500	53000	6.5
203	15800	64500	46500	6.6
209	16600	75500	56000	6.6

APPENDIX III

BIOCHEMICAL OXYGEN DEMAND DATA

Section A of this appendix gives the five-day BOD test data (BOD_{5T}), uncorrected for standard temperature, and the mean sample temperatures over the five day test period. For each sample, the BOD_{5T} is the average of the two duplicates (Hach units, A and B) unless otherwise noted. The sample temperature is the mean of 10 to 12 temperature (temp) readings over the five day test period.

The BOD data obtained for each sample, is shown in section B, which gives the corrected scale reading and the BOD (mg/l) at the time (in days and in hours) the Hach units were read. The dilution code for each sample is explained by the following example.

Example: 10 A 1

(a) (b) (c)

(a) dilution factor (DF): ml of animal waste sample diluted to 100 ml with dilution water.

(i) 10 ml: DF = 10X

(ii) 20 ml: DF = 5X

(iii) 25 ml: DF = 4X

(b) Volume conversion factor (VF): see section 4.3.2.3.

(i) A: VF = 4X

(ii) B: VF = 10X

(c) Pit number.

Therefore, the daily BOD readings are:

BOD (mg/l) = DF x VF x scale reading.

SECTION A: SAMPLE TEMPERATURE AND 5-DAY BOD VALUES.

Test day	Mean BOD_5 temp ^oC	Pit 1 BOD_{5T} mg/l	Pit 2 BOD_{5T} mg/l	Pit 3 BOD_{5T} mg/l	Pit 4 BOD_{5T} mg/l
79	23.5	3030[1]	3250	7280	8670
86	23.7	2410	5620	12500	12300
94	22.5	4300	5270	13600	12400
100	23.0	3970	5680	16000	12800
107	23.4	5000	5310	13900	14700
114	23.2	3790	3530	14700	16000
121	23.5	5340	7620	15200	13800
127	22.3	4510	5490	16700	14900
133	25.5	4130	6840	17600	15900
142	22.6	7620	8300	20100	18000
149	23.3	6510	8170	18700	19200
156	25.1	8300	9530	19000	19400
163	23.8	6840	8690	14400	16400
170	26.1	6900	7390	19700	19900
177	26.0	8890	9380	23200	21600
184	24.2	8760	11500	21800	20100
191	23.2	8970	9320	23400	21200
197	26.7	8120	9270	22500	20300
203	25.0	7220	11700[1]	23700	21400

[1] Only 1 sample obtained.

SECTION B: BOD TEST DATA.

6/4 1970	PIT 1	10A1	PIT 1	25B1
TIME	SCALE	BOD	SCALE	BOD
DAYS HOURS	READING	(MG/L)	READING	(MG/L)
0.70 16.75	NO DATA		10.	400.
0.90 21.58	OBTAINED		20.	800.
1.12 26.83			15.	600.
1.69 40.58			15.	600.
1.90 45.67			25.	1000.
2.69 64.58			40.	1600.
3.00 72.00			50.	2000.
3.68 88.42			60.	2400.
4.02 96.42			65.	2600.
4.78 114.75			90.	3600.
4.99 119.75			90.	3600.

R = .9160; R**2 = .8390

BOD = 3639.0 LOG HRS
+(-4537.1)

6/4 1970	PIT 2	10A2	PIT 2	25B2
TIME	SCALE	BOD	SCALE	BOD
DAYS HOURS	READING	(MG/L)	READING	(MG/L)
0.70 16.75	10.	400.	5.	200.
0.90 21.58	0.	0.	25.	1000.
1.12 26.83	5.	200.	25.	1000.
1.69 40.58	25.	1000.	35.	1400.
1.90 45.67	20.	800.	50.	2000.
2.69 64.58	40.	1600.	65.	2600.
3.00 72.00	60.	2400.	75.	3000.
3.68 88.42	85.	3400.	70.	2800.
4.02 96.42	75.	3000.	75.	3000.
4.78 114.75	75.	3000.	80.	3200.
4.99 119.75	75.	3000.	80.	3200.

R = .9364; R**2 = .8769

BOD = 4048.8 LOG HRS
+(-5280.9)

R = .9797; R**2 = .9598

BOD = 3496.2 LOG HRS
+(-3908.6)

6/4 1970	PIT 3	10A3	PIT 3	25B3
**********	*****	****	*****	****
TIME	SCALE	BOD	SCALE	BOD
DAYS HOURS	READING	(MG/L)	READING	(MG/L)
**** *****	*******	******	*******	******
0.70 16.75	105.	4200.	115.	4600.
0.90 21.58	135.	5400.	135.	5400.
1.12 26.83	150.	6000.	140.	5600.
1.69 40.58	175.	7000.	145.	5800.
1.90 45.67	175.	7000.	150.	6000.
2.69 64.58	185.	7400.	160.	6400.
3.00 72.00	190.	7600.	170.	6800.
3.68 88.42	175.	7000.	165.	6600.
4.02 96.42	180.	7200.	165.	6600.
4.78 114.75	170.	6800.	170.	6800.
4.99 119.75	180.	7200.	170.	6800.

R = .3214; R**2 = .6747 R = .9619; R**2 = .9252

BOD = 2216.8 LOG HRS BOD = 2315.3 LOG HRS
+(1755.2) +(2130.0)

6/4 1970	PIT 4	10A4	PIT 4	25B4
**********	*****	****	*****	****
TIME	SCALE	BOD	SCALE	BOD
DAYS HOURS	READING	(MG/L)	READING	(MG/L)
**** *****	*******	******	*******	******
0.70 16.75	85.	3400.	105.	4200.
0.90 21.58	140.	5600.	145.	5800.
1.12 26.83	155.	6200.	150.	6000.
1.69 40.58	170.	6800.	160.	6400.
1.90 45.67	170.	6800.	170.	6800.
2.69 64.58	190.	7600.	190.	7600.
3.00 72.00	180.	7200.	200.	8000.
3.68 88.42	175.	7000.	215.	8600.
4.02 96.42	185.	7400.	220.	8800.
4.78 114.75	185.	7400.	245.	9800.
4.99 119.75	185.	7400.	245.	9800.

R = .8484; R**2 = .7198 R = .9800; R**2 = .9604

BOD = 3478.3 LOG HRS BOD = 5031.9 LOG HRS
+(613.0) +(-2632.1)

13/4 1970	PIT 1	10A1	PIT 1	25B1
**********	*****	****	*****	****
TIME	SCALE	BOD	SCALE	BOD
DAYS HOURS	READING	(MG/L)	READING	(MG/L)
**** *****	*******	******	*******	******
0.46 11.00	0.	0.	0.	0.
0.76 18.25	0.	0.	5.	200.
1.45 34.75	0.	0.	10.	400.
1.80 43.25	0.	0.	10.	400.
2.47 59.33	0.	0.	25.	1000.
2.78 66.83	5.	200.	30.	1200.
3.48 83.58	15.	600.	50.	2000.
3.78 90.75	20.	800.	50.	2000.
4.54 109.00	50.	2000.	60.	2400.
4.78 114.83	50.	2000.	60.	2400.
5.44 130.58	110.	4400.	75.	3000.
5.90 141.50	120.	4800.	100.	4000.
	R = .6919; R**2 = .4787		R = .8883; R**2 = .7891	
	BOD = 3441.4 LOG HRS +(-4881.5)		BOD = 3184.3 LOG HRS +(-4074.6)	

13/4 1970	PIT 2	10A2	PIT 2	25B2
**********	*****	****	*****	****
TIME	SCALE	BOD	SCALE	BOD
DAYS HOURS	READING	(MG/L)	READING	(MG/L)
**** *****	*******	******	*******	******
0.46 11.00	0.	0.	0.	0.
0.76 18.25	10.	400.	5.	200.
1.45 34.75	20.	800.	20.	800.
1.80 43.25	35.	1400.	30.	1200.
2.47 59.33	65.	2600.	60.	2400.
2.78 66.83	75.	3000.	75.	3000.
3.48 83.58	80.	3200.	95.	3800.
3.78 90.75	95.	3800.	105.	4200.
4.54 109.00	115.	4600.	125.	5000.
4.78 114.83	130.	5200.	135.	5400.
5.44 130.58	230.	9200.	160.	6400.
5.90 141.50	260.	10400.	170.	6800.
	R = .8232; R**2 = .6777		R = .9337; R**2 = .8717	
	BOD = 7735.5 LOG HRS +(-10027.9)		BOD = 6361.5 LOG HRS +(-8036.6)	

13/4 197C	PIT 3	10A3	PIT 3	25B3
**********	*****	****	*****	****
TIME	SCALE	BOD	SCALE	BOD
DAYS HOURS	READING	(MG/L)	READING	(MG/L)
**** *****	*******	******	*******	******
0.46 11.00	20.	800.	40.	1600.
0.76 18.25	100.	4000.	125.	5000.
1.45 34.75	175.	7000.	155.	6200.
1.80 43.25	190.	7600.	165.	6600.
2.47 59.33	225.	9000.	170.	6800.
2.78 66.83	255.	10200.	190.	7600.
3.48 83.58	300.	12000.	230.	9200.
3.78 90.75	310.	12400.	240.	9600.
4.54 109.00	345.	13800.	260.	10400.
4.78 114.83	355.	14200.	270.	10800.
5.44 130.58	390.	15600.	300.	12000.
5.90 141.50	390.	15600.	315.	12600.
	R = .9917; R**2 = .9835		R = .9685; R**2 = .9379	
	BOD = 13282.5 LOG HRS +(-13417.3)		BOD = 8811.6 LOG HRS +(-7456.7)	

13/4 197C	PIT 4	10A4	PIT 4	25B4
**********	*****	****	*****	****
TIME	SCALE	BOD	SCALE	BOD
DAYS HOURS	READING	(MG/L)	READING	(MG/L)
**** *****	*******	******	*******	******
0.46 11.00	10.	400.	20.	800.
0.76 18.25	100.	4000.	90.	3600.
1.45 34.75	165.	6600.	160.	6400.
1.80 43.25	180.	7200.	165.	6600.
2.47 59.33	200.	8000.	185.	7400.
2.78 66.83	225.	9000.	200.	8000.
3.48 83.58	270.	10800.	250.	10000.
3.78 90.75	275.	11000.	265.	10600.
4.54 109.00	310.	12400.	285.	11400.
4.78 114.83	315.	12600.	290.	11600.
5.44 130.58	335.	13400.	330.	13200.
5.90 141.50	325.	13000.	370.	14800.
	R = .9919; R**2 = .9838		R = .9760; R**2 = .9526	
	BOD = 11364.0 LOG HRS +(-11158.5)		BOD = 11267.5 LOG HRS +(-11320.3)	

21/4 1970		PIT 1	20A1	PIT 1	25B1
**********		*****	****	*****	****
TIME		SCALE	BOD	SCALE	BOD
DAYS	HOURS	READING	(MG/L)	READING	(MG/L)
****	*****	*******	******	*******	******
0.72	17.25	15.	300.	10.	400.
1.01	24.33	35.	700.	15.	600.
1.70	40.83	65.	1300.	25.	1000.
2.03	48.67	95.	1900.	45.	1800.
2.72	65.17	105.	2100.	45.	1800.
3.02	72.42	130.	2600.	65.	2600.
3.75	90.00	185.	3700.	75.	3000.
3.99	95.67	210.	4200.	95.	3800.
4.82	115.67	260.	5200.	110.	4400.
5.04	120.92	280.	5600.	115.	4600.

R = .9361; R**2 = .8763 R = .9388; R**2 = .8814

BOD = 6037.3 LOG HRS +(-7911.5) BOD = 5029.9 LOG HRS +(-6490.8)

21/4 1970		PIT 2	20A2	PIT 2	25B2
**********		*****	****	*****	****
TIME		SCALE	BOD	SCALE	BOD
DAYS	HOURS	READING	(MG/L)	READING	(MG/L)
****	*****	*******	******	*******	******
0.72	17.25	35.	700.	15.	600.
1.01	24.33	55.	1100.	15.	600.
1.70	40.83	100.	2000.	30.	1200.
2.03	48.67	125.	2500.	60.	2400.
2.72	65.17	165.	3300.	65.	2600.
3.02	72.42	180.	3600.	90.	3600.
3.75	90.00	230.	4600.	110.	4400.
3.99	95.67	240.	4800.	130.	5200.
4.82	115.67	270.	5400.	140.	5600.
5.04	120.92	275.	5500.	150.	6000.

R = .9818; R**2 = .9639 R = .9492; R**2 = .9009

BOD = 5967.9 LOG HRS +(-7198.7) BOD = 6795.8 LOG HRS +(-8792.0)

21/4 1970		PIT 3	10A3	PIT 3	25B3
**********		*****	****	*****	****
TIME		SCALE	BOD	SCALE	BOD
DAYS	HOURS	READING	(MG/L)	READING	(MG/L)
****	*****	*******	******	*******	******
0.72	17.25	85.	3400.	135.	5400.
1.01	24.33	165.	6600.	170.	6800.
1.70	40.83	195.	7800.	190.	7600.
2.03	48.67	230.	9200.	220.	8800.
2.72	65.17	220.	8800.	230.	9200.
3.02	72.42	260.	10400.	250.	10000.
3.75	90.00	315.	12600.	290.	11600.
3.99	95.67	335.	13400.	310.	12400.
4.82	115.67	375.	15000.	335.	13400.
5.04	120.92	385.	15400.	340.	13600.

R = .9647; R**2 = .9307 R = .9686; R**2 = .9381

BOD = 13019.3 LOG HRS +(-12752.7) BOD = 9577.1 LOG HRS +(-7048.4)

21/4 1970		PIT 4	10A4	PIT 4	25B4
**********		*****	****	*****	****
TIME		SCALE	BOD	SCALE	BOD
DAYS	HOURS	READING	(MG/L)	READING	(MG/L)
****	*****	*******	******	*******	******
0.72	17.25	80.	3200.	100.	4000.
1.01	24.33	155.	6200.	150.	6000.
1.70	40.83	190.	7600.	170.	6800.
2.03	48.67	200.	8000.	195.	7800.
2.72	65.17	235.	9400.	195.	7800.
3.02	72.42	255.	10200.	220.	8800.
3.75	90.00	315.	12600.	250.	10000.
3.99	95.67	325.	13000.	270.	10800.
4.82	115.67	350.	14000.	280.	11200.
5.04	120.92	360.	14400.	290.	11600.

R = .9803; R**2 = .9610 R = .9763; R**2 = .9531

BOD = 12611.5 LOG HRS +(-12431.8) BOD = 8433.0 LOG HRS +(-6426.0)

27/4 1970	PIT 1	20A1	PIT 1	25B1
**********	*****	****	*****	****
TIME	SCALE	BOD	SCALE	BOD
DAYS HOURS	READING	(MG/L)	READING	(MG/L)
**** *****	*******	******	*******	******
0.67 16.00	10.	200.	5.	200.
0.99 23.67	40.	800.	15.	600.
1.66 39.92	35.	700.	30.	1200.
2.00 48.08	75.	1500.	40.	1600.
2.67 64.08	85.	1700.	50.	2000.
3.00 72.08	130.	2600.	70.	2800.
3.67 88.00	140.	2800.	80.	3200.
4.00 96.08	160.	3200.	85.	3400.
4.78 114.67	200.	4000.	110.	4400.
5.00 120.08	215.	4300.	110.	4400.
5.72 137.33	250.	5000.	125.	5000.
	R = .9334; R**2 = .8712		R = .9616; R**2 = .9247	
	BOD = 4935.4 LOG HRS +(-6415.8)		BOD = 5185.1 LOG HRS +(-6681.8)	

27/4 1970	PIT 2	20A2	PIT 2	25B2
**********	*****	****	*****	****
TIME	SCALE	BOD	SCALE	BOD
DAYS HOURS	READING	(MG/L)	READING	(MG/L)
**** *****	*******	******	*******	******
0.67 16.00	35.	700.	25.	1000.
0.99 23.67	55.	1100.	35.	1400.
1.66 39.92	95.	1900.	50.	2000.
2.00 48.08	120.	2400.	70.	2800.
2.67 64.08	165.	3300.	100.	4000.
3.00 72.08	175.	3500.	105.	4200.
3.67 88.00	220.	4400.	140.	5600.
4.00 96.08	230.	4600.	140.	5600.
4.78 114.67	260.	5200.	165.	6600.
5.00 120.08	265.	5300.	165.	6600.
5.72 137.33	275.	5500.	180.	7200.
	R = .9826; R**2 = .9655		R = .9678; R**2 = .9367	
	BOD = 5607.9 LOG HRS +(-6613.1)		BOD = 7137.3 LOG HRS +(-8528.8)	

27/4 1970		PIT 3	10A3	PIT 3	25B3
**********		*****	****	*****	****
TIME		SCALE	BOD	SCALE	BOD
DAYS	HOURS	READING	(MG/L)	READING	(MG/L)
****	*****	*******	******	*******	******
0.67	16.00	85.	3400.	110.	4400.
0.99	23.67	180.	7200.	180.	7200.
1.66	39.92	220.	8800.	230.	9200.
2.00	48.08	250.	10000.	245.	9800.
2.67	64.08	280.	11200.	275.	11000.
3.00	72.08	320.	12800.	300.	12000.
3.67	88.00	340.	13600.	360.	14400.
4.00	96.08	370.	14800.	370.	14800.
4.78	114.67	410.	16400.	400.	16000.
5.00	120.08	420.	16800.	405.	16200.
5.72	137.33	435.	17400.	415.	16600.
		R = .9892; R**2 = .9785		R = .9878; R**2 = .9758	
		BOD = 14487.3 LOG HRS +(-13949.2)		BOD = 13240.6 LOG HRS +(-11784.9)	

27/4 1970		PIT 4	10A4	PIT 4	25B4
**********		*****	****	*****	****
TIME		SCALE	BOD	SCALE	BOD
DAYS	HOURS	READING	(MG/L)	READING	(MG/L)
****	*****	*******	******	*******	******
0.67	16.00	65.	2600.	110.	4400.
0.99	23.67	160.	6400.	175.	7000.
1.66	39.92	195.	7800.	200.	8000.
2.00	48.08	205.	8200.	220.	8800.
2.67	64.08	235.	9400.	235.	9400.
3.00	72.08	245.	9800.	240.	9600.
3.67	88.00	290.	11600.	285.	11400.
4.00	96.08	310.	12400.	295.	11800.
4.78	114.67	335.	13400.	315.	12600.
5.00	120.08	335.	13400.	320.	12800.
5.72	137.33	340.	13600.	325.	13000.
		R = .9844; R**2 = .9691		R = .9849; R**2 = .9700	
		BOD = 11346.1 LOG HRS +(-10477.8)		BOD = 8957.6 LOG HRS +(-6175.5)	

4/5 1970	PIT 1	20A1	PIT 1	25B1
**********	*****	****	*****	****
TIME	SCALE	BOD	SCALE	BOD
DAYS HOURS	READING	(MG/L)	READING	(MG/L)
**** *****	*******	******	*******	******
0.71 17.00	10.	200.	0.	0.
1.05 25.17	30.	600.	0.	0.
1.70 40.83	75.	1500.	30.	1200.
2.09 50.08	105.	2100.	50.	2000.
2.71 65.08	140.	2800.	65.	2600.
3.08 73.83	160.	3200.	90.	3600.
3.70 88.83	185.	3700.	110.	4400.
4.09 98.25	190.	3800.	120.	4800.
4.77 114.58	220.	4400.	155.	6200.
5.06 121.50	220.	4400.	165.	6600.
5.73 137.42	230.	4600.	165.	5600.

R = .9923; R**2 = .9846 R = .9604; R**2 = .9223

BOD = 5264.9 LOG HRS +(-6653.4) BOD = 8165.2 LOG HRS +(-11277.1)

4/5 1970	PIT 2	20A2	PIT 2	25B2
**********	*****	****	*****	****
TIME	SCALE	BOD	SCALE	BOD
DAYS HOURS	READING	(MG/L)	READING	(MG/L)
**** *****	*******	******	*******	******
0.71 17.00	60.	1200.	0.	0.
1.05 25.17	85.	1700.	0.	0.
1.70 40.83	125.	2500.	30.	1200.
2.09 50.08	145.	2900.	50.	2000.
2.71 65.08	180.	3600.	70.	2800.
3.08 73.83	190.	3800.	80.	3200.
3.70 88.83	215.	4300.	105.	4200.
4.09 98.25	230.	4600.	115.	4600.
4.77 114.58	260.	5200.	155.	6200.
5.06 121.50	265.	5300.	150.	6000.
5.73 137.42	270.	5400.	175.	7000.

R = .9896; R**2 = .9794 R = .9579; R**2 = .9177

BOD = 4928.2 LOG HRS +(-5209.6) BOD = 8019.2 LOG HRS +(-11086.4)

4/5 1970		PIT 3	10A3	PIT 3	2563
**********		*****	****	*****	****
TIME		SCALE	BOD	SCALE	BOD
DAYS	HOURS	READING	(MG/L)	READING	(MG/L)
****	*****	*******	******	*******	******
0.71	17.00	45.	1800.	65.	2600.
1.05	25.17	155.	6200.	140.	5600.
1.70	40.83	195.	7800.	205.	8200.
2.09	50.08	215.	8600.	230.	9200.
2.71	65.08	245.	9800.	255.	10200.
3.08	73.83	265.	10600.	280.	11200.
3.70	88.83	290.	11600.	320.	12800.
4.09	98.25	290.	11600.	340.	13600.
4.77	114.58	330.	13200.	370.	14800.
5.06	121.50	330.	13200.	380.	15200.
5.73	137.42	335.	13400.	395.	15800.

R = .3364; R**2 = .9730 R = .9958; R**2 = .9915

BOD = 11951.5 LOG HRS +(-11762.9) BOD = 14294.1 LOG HRS +(-14953.1)

4/5 1970		PIT 4	10A4	PIT 4	2534
**********		*****	****	*****	****
TIME		SCALE	BOD	SCALE	BOD
DAYS	HOURS	READING	(MG/L)	READING	(MG/L)
****	*****	*******	******	*******	******
0.71	17.00	75.	3000.	70.	2800.
1.05	25.17	185.	7400.	150.	6000.
1.70	40.83	210.	8400.	200.	8000.
2.09	50.08	235.	9400.	225.	9000.
2.71	65.08	265.	10600.	255.	10200.
3.08	73.83	285.	11400.	280.	11200.
3.70	88.83	320.	12800.	320.	12800.
4.09	98.25	345.	13800.	335.	13400.
4.77	114.58	385.	15400.	365.	14600.
5.06	121.50	395.	15800.	370.	14800.
5.73	137.42	400.	16000.	380.	15200.

R = .9833; R**2 = .9669 R = .9952; R**2 = .9903

BOD = 13624.4 LOG HRS +(-13308.6) BOD = 13572.3 LOG HRS +(-13759.9)

11/5 1970	PIT 1	20A1	PIT 1	25B1
**********	*****	****	*****	****
TIME	SCALE	BOD	SCALE	BOD
DAYS HOURS	READING	(MG/L)	READING	(MG/L)
**** *****	*******	******	*******	******
0.62 14.83	35.	700.	10.	400.
0.99 23.83	60.	1200.	15.	600.
1.62 38.92	90.	1800.	25.	1000.
1.97 47.25	135.	2700.	45.	1800.
2.63 63.17	190.	3800.	40.	1600.
3.00 72.08	215.	4300.	45.	1800.
3.62 87.00	245.	4900.	40.	1600.
3.99 95.67	260.	5200.	55.	2200.
4.66 111.83	285.	5700.	55.	2200.
5.76 138.17	300.	6000.	50.	2000.
5.83 139.92	295.	5900.	40.	1600.
	R = .9808; R**2 = .9619		R = .8783; R**2 = .7714	
	BOD = 6075.2 LOG HRS +(-7058.3)		BOD = 1701.4 LOG HRS +(-1523.9)	

11/5 1970	PIT 2	20A2	PIT 2	25B2
**********	*****	****	*****	****
TIME	SCALE	BOD	SCALE	BOD
DAYS HOURS	READING	(MG/L)	READING	(MG/L)
**** *****	*******	******	*******	******
0.62 14.83	5.	100.	10.	400.
0.99 23.83	25.	500.	30.	1200.
1.62 38.92	55.	1100.	40.	1600.
1.97 47.25	60.	1200.	50.	2000.
2.63 63.17	115.	2300.	65.	2600.
3.00 72.08	130.	2600.	55.	2200.
3.62 87.00	150.	3000.	65.	2600.
3.99 95.67	175.	3500.	70.	2800.
4.66 111.83	220.	4400.	65.	2600.
5.76 138.17	290.	5800.	60.	2400.
5.83 139.92	285.	5700.	55.	2200.
	R = .9359; R**2 = .8759		R = .8876; R**2 = .7879	
	BOD = 5868.8 LOG HRS +(-7779.0)		BOD = 2055.1 LOG HRS +(-1630.9)	

11/5 1970		PIT 3	10A3	PIT 3	2583
**********		*****	****	*****	****
TIME		SCALE	BOD	SCALE	BOD
DAYS	HOURS	READING	(MG/L)	READING	(MG/L)
****	*****	*******	******	*******	******
0.62	14.83	75.	3000.	135.	5400.
0.99	23.83	190.	7600.	210.	8400.
1.62	38.92	230.	9200.	240.	9600.
1.97	47.25	270.	10800.	255.	10200.
2.63	63.17	310.	12400.	295.	11800.
3.00	72.08	330.	13200.	305.	12200.
3.62	87.00	345.	13800.	325.	13000.
3.99	95.67	355.	14200.	330.	13200.
4.66	111.83	360.	14400.	350.	14000.
5.76	138.17	365.	14600.	395.	15800.
5.83	139.92	355.	14200.	380.	15200.

R = .9705; R**2 = .9418 R = .9924; R**2 = .9848

BOD = 11343.2 LOG HRS +(-8759.9) BOD = 9779.6 LOG HRS +(-5828.6)

11/5 1970		PIT 4	10A4	PIT 4	1084
**********		*****	****	*****	****
TIME		SCALE	BOD	SCALE	BOD
DAYS	HOURS	READING	(MG/L)	READING	(MG/L)
****	*****	*******	******	*******	******
0.62	14.83	55.	2200.	50.	5000.
0.99	23.83	180.	7200.	105.	10500.
1.62	38.92	220.	8800.	130.	13000.
1.97	47.25	230.	9200.	130.	13000.
2.63	63.17	270.	10800.	150.	15000.
3.00	72.08	285.	11400.	155.	15500.
3.62	87.00	315.	12600.	160.	16000.
3.99	95.67	340.	13600.	160.	16000.
4.66	111.83	375.	15000.	160.	16000.
5.76	138.17	430.	17200.	165.	16500.
5.83	139.92	420.	16800.	155.	15500.

R = .9833; R**2 = .9669 R = .9296; R**2 = .8642

BOD = 13370.1 LOG HRS +(-13527.8) BOD = 10195.4 LOG HRS +(-4465.3)

18/5 1970	PIT 1	20A1	PIT 1	25B1
**********	*****	****	*****	****
TIME	SCALE	BOD	SCALE	BOD
DAYS HOURS	READING	(MG/L)	READING	(MG/L)
**** *****	*******	******	*******	******
0.63 15.17	55.	1100.	15.	600.
0.99 23.67	90.	1800.	45.	1800.
1.63 39.08	140.	2800.	75.	3000.
2.00 48.08	170.	3400.	90.	3600.
2.63 63.17	225.	4500.	90.	3600.
3.00 71.92	250.	5000.	90.	3600.
3.63 87.17	285.	5700.	100.	4000.
4.00 96.00	300.	6000.	100.	4000.
4.65 111.58	305.	6100.	95.	3800.
5.02 120.42	315.	6300.	100.	4000.
	R = .9885; R**2 = .9771		R = .9422; R**2 = .8877	
	BOD = 6281.0 LOG HRS +(-6745.3)		BOD = 3583.2 LOG HRS +(-3084.0)	

18/5 1970	PIT 2	20A2	PIT 2	25B2
**********	*****	****	*****	****
TIME	SCALE	BOD	SCALE	BOD
DAYS HOURS	READING	(MG/L)	READING	(MG/L)
**** *****	*******	******	*******	******
0.63 15.17	50.	1000.	40.	1600.
0.99 23.67	90.	1800.	60.	2400.
1.63 39.08	150.	3000.	95.	3800.
2.00 48.08	170.	3400.	120.	4800.
2.63 63.17	210.	4200.	155.	6200.
3.00 71.92	225.	4500.	170.	6800.
3.63 87.17	255.	5100.	200.	8000.
4.00 96.00	270.	5400.	225.	9000.
4.65 111.58	300.	6000.	235.	9400.
5.02 120.42	300.	6000.	245.	9800.
	R = .9954; R**2 = .9909		R = .9798; R**2 = .9600	
	BOD = 5757.3 LOG HRS +(-6056.8)		BOD = 9693.0 LOG HRS +(-10818.9)	

13/5 1970	PIT 3	10A3	PIT 3	20B3
**********	*****	****	*****	****
TIME	SCALE	BOD	SCALE	BOD
DAYS HOURS	READING	(MG/L)	READING	(MG/L)
**** *****	*******	******	*******	******
0.63 15.17	105.	4200.	120.	6000.
0.99 23.67	240.	9600.	160.	8000.
1.63 39.08	275.	11000.	185.	9250.
2.00 48.08	295.	11800.	200.	10000.
2.63 63.17	320.	12800.	215.	10750.
3.00 71.92	335.	13400.	215.	10750.
3.63 87.17	360.	14400.	245.	12250.
4.00 96.00	375.	15000.	270.	13500.
4.65 111.58	430.	17200.	275.	13750.
5.02 120.42	435.	17400.	280.	14000.
	R = .9744; R**2 = .9495		R = .9817; R**2 = .9638	
	BOD = 12759.5 LOG HRS +(-9696.8)		BOD = 8679.4 LOG HRS +(-4396.4)	

18/5 1970	PIT 4	10A4	PIT 4	20B4
**********	*****	****	*****	****
TIME	SCALE	BOD	SCALE	BOD
DAYS HOURS	READING	(MG/L)	READING	(MG/L)
**** *****	*******	******	*******	******
0.63 15.17	90.	3600.	90.	4500.
0.99 23.67	200.	8000.	155.	7750.
1.63 39.08	240.	9600.	180.	9000.
2.00 48.08	245.	9800.	195.	9750.
2.63 63.17	290.	11600.	205.	10250.
3.00 71.92	305.	12200.	210.	10500.
3.63 87.17	345.	13800.	220.	11000.
4.00 96.00	350.	14000.	240.	12000.
4.65 111.58	360.	14400.	240.	12000.
5.02 120.42	380.	15200.	245.	12250.
	R = .9865; R**2 = .9732		R = .9783; R**2 = .9571	
	BOD = 11828.5 LOG HRS +(-9524.1)		BOD = 7801.4 LOG HRS +(-3781.6)	

24/5 1970	PIT 1	20A1	PIT 1	25B1
**********	*****	****	*****	****
TIME	SCALE	BOD	SCALE	BOD
DAYS HOURS	READING	(MG/L)	READING	(MG/L)
**** *****	*******	******	*******	******
0.60 14.42	20.	400.	30.	1200.
0.96 23.00	55.	1100.	50.	2000.
1.60 38.33	90.	1800.	50.	2000.
1.92 46.17	120.	2400.	75.	3000.
2.59 62.25	170.	3400.	95.	3800.
2.95 70.75	190.	3800.	105.	4200.
3.59 86.25	210.	4200.	105.	4200.
3.96 95.08	200.	4000.	110.	4400.
4.59 110.08	220.	4400.	110.	4400.
4.96 119.08	220.	4400.	100.	4000.
5.03 120.75	225.	4500.	100.	4000.
	R = .9876; R**2 = .9753		R = .9406; R**2 = .8847	
	BOD = 4742.5 LOG HRS +(-5291.0)		BOD = 3530.6 LOG HRS +(-2885.3)	

24/5 1970	PIT 2	20A2	PIT 2	25B2
**********	*****	****	*****	****
TIME	SCALE	BOD	SCALE	BOD
DAYS HOURS	READING	(MG/L)	READING	(MG/L)
**** *****	*******	******	*******	******
0.60 14.42	45.	900.	30.	1200.
0.96 23.00	85.	1700.	55.	2200.
1.60 38.33	150.	3000.	55.	2200.
1.92 46.17	170.	3400.	85.	3400.
2.59 62.25	225.	4500.	110.	4400.
2.95 70.75	250.	5000.	110.	4400.
3.59 86.25	280.	5600.	110.	4400.
3.96 95.08	275.	5500.	110.	4400.
4.59 110.08	305.	6100.	110.	4400.
4.96 119.08	320.	6400.	105.	4200.
5.03 120.75	325.	6500.	105.	4200.
	R = .9945; R**2 = .9891		R = .9252; R**2 = .8560	
	BOD = 6263.9 LOG HRS +(-6700.7)		BOD = 3545.6 LOG HRS +(-2713.6)	

24/5 1970	PIT 3	10A3	PIT 3	20B3
**********	*****	****	*****	****
TIME	SCALE	BOD	SCALE	BOD
DAYS HOURS	READING	(MG/L)	READING	(MG/L)
**** *****	*******	******	*******	******
0.60 14.42	70.	2800.	110.	5500.
0.96 23.00	190.	7600.	190.	9500.
1.60 38.33	270.	10800.	200.	10000.
1.92 46.17	300.	12000.	220.	11000.
2.59 62.25	350.	14000.	255.	12750.
2.95 70.75	370.	14800.	260.	13000.
3.59 86.25	410.	16400.	290.	14500.
3.96 95.08	405.	16200.	290.	14500.
4.59 110.08	415.	16600.	310.	15500.
4.96 119.08	440.	17600.	305.	15250.
5.03 120.75	440.	17600.	305.	15250.
R = .9920; R**2 = .9841			R = .9852; R**2 = .9706	
BOD = 15249.3 LOG HRS +(-13760.4)			BOD = 10169.4 LOG HRS +(-5619.6)	

24/5 1970	PIT 4	10A4	PIT 4	20B4
**********	*****	****	*****	****
TIME	SCALE	BOD	SCALE	POD
DAYS HOURS	READING	(MG/L)	READING	(MG/L)
**** *****	*******	******	*******	******
0.60 14.42	65.	2600.	70.	3500.
0.96 23.00	195.	7800.	150.	7500.
1.60 38.33	260.	10400.	160.	8000.
1.92 46.17	285.	11400.	180.	9000.
2.59 62.25	325.	13000.	195.	9750.
2.95 70.75	340.	13600.	200.	10000.
3.59 86.25	385.	15400.	225.	11250.
3.96 95.08	380.	15200.	235.	11750.
4.59 110.08	395.	15800.	255.	12750.
4.96 119.08	410.	16400.	270.	13500.
5.03 120.75	415.	16600.	270.	13500.
R = .9888; R**2 = .9778			R = .9773; R**2 = .9551	
BOD = 13989.3 LOG HRS +(-12268.2)			BOD = 9636.3 LOG HRS +(-7059.6)	

30/5 1970	PIT 1	20A1	PIT 1	25B1
**********	*****	****	*****	****
TIME	SCALE	BOD	SCALE	BOD
DAYS HOURS	READING	(MG/L)	READING	(MG/L)
**** *****	*******	******	*******	******
0.81 19.45	65.	1300.	35.	1400.
0.98 23.50	75.	1500.	45.	1800.
1.23 29.45	105.	2100.	50.	2000.
1.72 41.33	145.	2900.	90.	3600.
2.02 48.50	155.	3100.	90.	3600.
2.71 65.00	225.	4500.	90.	3600.
3.06 73.50	205.	4100.	90.	3600.
3.71 89.00	235.	4700.	110.	4400.
4.04 96.92	200.	4000.	70.	2800.
4.71 113.00	190.	3800.	80.	3200.
5.04 121.00	185.	3700.	75.	3000.
R = .8892; R**2 = .7907			R = .5856; R**2 = .4700	
BOD = 3756.7 LOG HRS +(-3305.4)			BOD = 2271.5 LOG HRS +(-961.0)	

30/5 1970	PIT 2	20A2	PIT 2	25B2
**********	*****	****	*****	****
TIME	SCALE	BOD	SCALE	BOD
DAYS HOURS	READING	(MG/L)	READING	(MG/L)
**** *****	*******	******	*******	******
0.81 19.45	60.	1200.	35.	1400.
0.98 23.50	70.	1400.	45.	1800.
1.23 29.45	95.	1900.	50.	2000.
1.72 41.33	135.	2700.	95.	3800.
2.02 48.50	140.	2800.	115.	4600.
2.71 65.00	215.	4300.	145.	5800.
3.06 73.50	220.	4400.	145.	5800.
3.71 89.00	280.	5600.	190.	7600.
4.04 96.92	265.	5300.	170.	6800.
4.71 113.00	280.	5600.	195.	7800.
5.04 121.00	295.	5900.	180.	7200.
R = .9865; R**2 = .9732			R = .9833; R**2 = .9668	
BOD = 6354.1 LOG HRS +(-7344.0)			BOD = 8501.5 LOG HRS +(-9861.3)	

30/5 1970	PIT 3	10A3	PIT 3	20B3
**********	*****	****	*****	****
TIME	SCALE	BOD	SCALE	BOD
DAYS HOURS	READING	(MG/L)	READING	(MG/L)
**** *****	*******	******	*******	******
0.81 19.45	165.	6600.	175.	8750.
0.98 23.50	220.	8800.	195.	9750.
1.23 29.45	255.	10200.	210.	10500.
1.72 41.33	285.	11400.	245.	12250.
2.02 48.50	290.	11600.	265.	13250.
2.71 65.00	355.	14200.	300.	15000.
3.06 73.50	355.	14200.	310.	15500.
3.71 89.00	415.	16600.	350.	17500.
4.04 96.92	420.	16800.	330.	16500.
4.71 113.00	420.	16800.	345.	17250.
5.04 121.00	435.	17400.	335.	16750.
	R = .9888; R**2 = .9777		R = .9855; R**2 = .9712	
	BOD = 13062.4 LOG HRS +(-9632.9)		BOD = 11284.8 LOG HRS +(-5769.6)	

30/5 1970	PIT 4	10A4	PIT 4	20B4
**********	*****	****	*****	****
TIME	SCALE	BOD	SCALE	BOD
DAYS HOURS	READING	(MG/L)	READING	(MG/L)
**** *****	*******	******	*******	******
0.81 19.45	130.	5200.	115.	5750.
0.98 23.50	210.	8400.	145.	7250.
1.23 29.45	240.	9600.	160.	8000.
1.72 41.33	270.	10800.	195.	9750.
2.02 48.50	300.	12000.	200.	10000.
2.71 65.00	345.	13800.	230.	11500.
3.06 73.50	370.	14800.	240.	12000.
3.71 89.00	385.	15400.	295.	14750.
4.04 96.92	405.	16200.	280.	14000.
4.71 113.00	410.	16400.	280.	14000.
5.04 121.00	445.	17800.	260.	13000.
	R = .9889; R**2 = .9779		R = .9680; R**2 = .9370	
	BOD = 13929.2 LOG HRS +(-11526.3)		BOD = 10472.2 LOG HRS +(-7352.5)	

8/6 1970	PIT 1	20A1	PIT 1	25B1
**********	*****	****	*****	****
TIME	SCALE	BOD	SCALE	BOD
DAYS HOURS	READING	(MG/L)	READING	(MG/L)
**** *****	*******	******	*******	******
0.69 16.50	105.	2100.	55.	2200.
1.03 24.83	135.	2700.	75.	3000.
1.69 40.50	155.	3100.	115.	4600.
2.04 48.92	180.	3600.	125.	5000.
2.25 54.00	200.	4000.	145.	5800.
2.69 64.50	215.	4300.	165.	6600.
3.03 72.75	255.	5100.	170.	6800.
3.69 88.50	265.	5300.	205.	8200.
4.04 97.00	280.	5600.	205.	8200.
4.71 113.00	310.	6200.	240.	9600.
4.99 119.67	320.	6400.	245.	9800.
	R = .9711; R**2 = .9431		R = .9815; R**2 = .9633	
	BOD = 5121.8 LOG HRS +(-4622.7)		BOD = 9053.8 LOG HRS +(-9604.0)	

8/6 1970	PIT 2	20A2	PIT 2	25B2
**********	*****	****	*****	****
TIME	SCALE	BOD	SCALE	BOD
DAYS HOURS	READING	(MG/L)	READING	(MG/L)
**** *****	*******	******	*******	******
0.69 16.50	110.	2200.	65.	2600.
1.03 24.83	145.	2900.	80.	3200.
1.69 40.50	150.	3000.	125.	5000.
2.04 48.92	170.	3400.	155.	6200.
2.25 54.00	180.	3600.	175.	7000.
2.69 64.50	175.	3500.	195.	7800.
3.03 72.75	220.	4400.	210.	8400.
3.69 88.50	215.	4300.	250.	10000.
4.04 97.00	235.	4700.	260.	10400.
4.71 113.00	250.	5000.	305.	12200.
4.99 119.67	285.	5700.	315.	12600.
	R = .9404; R**2 = .8843		R = .9734; R**2 = .9475	
	BOD = 3568.5 LOG HRS +(-2404.5)		BOD = 12037.0 LOG HRS +(-13441.1)	

8/6 1970	PIT 3	10A3	PIT 3	20B3
**********	*****	****	*****	****
TIME	SCALE	BOD	SCALE	BOD
DAYS HOURS	READING	(MG/L)	READING	(MG/L)
**** *****	*******	******	*******	******
0.69 16.50	225.	9000.	220.	11000.
1.03 24.83	280.	11200.	260.	13000.
1.69 40.50	310.	12400.	310.	15500.
2.04 48.92	310.	12400.	345.	17250.
2.25 54.00	320.	12800.	360.	18000.
2.69 64.50	350.	14000.	380.	19000.
3.03 72.75	370.	14800.	400.	20000.
3.69 88.50	405.	16200.	410.	20500.
4.04 97.00	415.	16600.	410.	20500.
4.71 113.00	450.	18000.	455.	22750.
4.99 119.67	470.	18800.	465.	23250.
R = .9652; R**2 = .9316			R = .9929; R**2 = .9859	
BOD = 10633.7 LOG HRS +(-4541.4)			BOD = 14004.0 LOG HRS +(-6419.8)	

8/6 1970	PIT 4	10A4	PIT 4	20B4
**********	*****	****	*****	****
TIME	SCALE	BOD	SCALE	BOD
DAYS HOURS	READING	(MG/L)	READING	(MG/L)
**** *****	*******	******	*******	******
0.69 16.50	185.	7400.	120.	6000.
1.03 24.83	270.	10800.	190.	9500.
1.69 40.50	305.	12200.	255.	12750.
2.04 48.92	315.	12600.	275.	13750.
2.25 54.00	330.	13200.	295.	14750.
2.69 64.50	315.	12600.	310.	15500.
3.03 72.75	355.	14200.	325.	16250.
3.69 88.50	345.	13800.	365.	18250.
4.04 97.00	370.	14800.	375.	18750.
4.71 113.00	385.	15400.	395.	19750.
4.99 119.67	425.	17000.	400.	20000.
R = .9587; R**2 = .9191			R = .9984; R**2 = .9967	
BOD = 8912.3 LOG HRS +(-2609.2)			BOD = 16048.6 LOG HRS +(-13249.0)	

15/6 1970	PIT 1	20A1	PIT 1	25B1
**********	*****	****	*****	****

TIME		SCALE	BOD	SCALE	BOD
DAYS	HOURS	READING	(MG/L)	READING	(MG/L)
****	*****	*******	******	*******	******
0.67	16.00	80.	1600.	55.	2200.
1.03	24.75	100.	2000.	70.	2800.
1.68	40.25	145.	2900.	110.	4400.
2.06	49.50	170.	3400.	105.	4200.
2.68	64.25	220.	4400.	130.	5200.
3.02	72.50	235.	4700.	130.	5200.
3.69	88.50	290.	5800.	145.	5800.
4.06	97.50	315.	6300.	135.	5400.
4.75	114.00	370.	7400.	160.	6400.
5.00	120.00	365.	7300.	155.	6200.

R = .9600; R**2 = .9216 R = .9831; R**2 = .9664

BOD = 6923.3 LOG HRS +(-7630.9)

BOD = 4710.1 LOG HRS +(-3527.3)

15/6 1970	PIT 2	20A2	PIT 2	25B2
**********	*****	****	*****	****

TIME		SCALE	BOD	SCALE	BOD
DAYS	HOURS	READING	(MG/L)	READING	(MG/L)
****	*****	*******	******	*******	******
0.67	16.00	80.	1600.	75.	3000.
1.03	24.75	95.	1900.	100.	4000.
1.68	40.25	120.	2400.	130.	5200.
2.06	49.50	135.	2700.	140.	5600.
2.68	64.25	185.	3700.	190.	7600.
3.02	72.50	200.	4000.	195.	7800.
3.69	88.50	260.	5200.	235.	9400.
4.06	97.50	265.	5300.	235.	9400.
4.75	114.00	325.	6500.	275.	11000.
5.00	120.00	335.	6700.	280.	11200.

R = .9336; R**2 = .8717 R = .9705; R**2 = .9419

BOD = 5975.0 LOG HRS +(-6533.2)

BOD = 9606.9 LOG HRS +(-9523.9)

15/6 1970	PIT 3	10A3	PIT 3	20B3
**********	*****	****	*****	****
TIME	SCALE	BOD	SCALE	BOD
DAYS HOURS	READING	(MG/L)	READING	(MG/L)
**** *****	*******	******	*******	******
0.67 16.00	95.	3800.	95.	4750.
1.03 24.75	250.	10000.	155.	7750.
1.68 40.25	285.	11400.	250.	12500.
2.06 49.50	300.	12000.	250.	12500.
2.68 64.25	345.	13800.	295.	14750.
3.02 72.50	365.	14600.	305.	15250.
3.69 88.50	400.	16000.	340.	17000.
4.06 97.50	405.	16200.	355.	17750.
4.75 114.00	450.	18000.	390.	19500.
5.00 120.00	445.	17800.	390.	19500.
	R = .9794; R**2 = .9592		R = .9956; R**2 = .9913	
	BOD = 14479.0 LOG HRS +(-12177.0)		BOD = 16718.7 LOG HRS +(-15362.3)	

15/6 1970	PIT 4	10A4	PIT 4	20B4
**********	*****	****	*****	****
TIME	SCALE	BOD	SCALE	BOD
DAYS HOURS	READING	(MG/L)	READING	(MG/L)
**** *****	*******	******	*******	******
0.67 16.00	160.	6400.	125.	6250.
1.03 24.75	255.	10200.	215.	10750.
1.68 40.25	285.	11400.	265.	13250.
2.06 49.50	310.	12400.	280.	14000.
2.68 64.25	350.	14000.	330.	16500.
3.02 72.50	385.	15400.	345.	17250.
3.69 88.50	400.	16000.	380.	19000.
4.06 97.50	430.	17200.	375.	18750.
4.75 114.00	445.	17800.	400.	20000.
5.00 120.00	460.	18400.	395.	19750.
	R = .9904; R**2 = .9810		R = .9929; R**2 = .9859	
	BOD = 13015.0 LOG HRS +(-9034.9)		BOD = 15293.2 LOG HRS +(-11423.2)	

22/6 1970		PIT 1	20A1	PIT 1	25B1
**********		*****	****	*****	****
TIME		SCALE	BOD	SCALE	BOD
DAYS	HOURS	READING	(MG/L)	READING	(MG/L)
****	*****	*******	******	*******	******
0.65	15.50	90.	1800.	65.	2600.
1.00	24.00	105.	2100.	80.	3200.
1.65	39.50	180.	3600.	115.	4600.
2.00	48.00	195.	3900.	130.	5200.
2.65	63.50	265.	5300.	150.	6000.
3.00	72.00	275.	5500.	175.	7000.
3.62	87.00	315.	6300.	205.	8200.
4.00	96.00	320.	6400.	220.	8800.
4.73	113.50	350.	7000.	250.	10000.
5.00	120.00	370.	7400.	265.	10600.

R = .9856; R**2 = .9714 R = .9626; R**2 = .9266

BOD = 6636.7 LOG HRS +(-6727.0) BOD = 9033.6 LOG HRS +(-9247.0)

22/6 1970		PIT 2	20A2	PIT 2	25B2
**********		*****	****	*****	****
TIME		SCALE	BOD	SCALE	BOD
DAYS	HOURS	READING	(MG/L)	READING	(MG/L)
****	*****	*******	******	*******	******
0.65	15.50	160.	3200.	90.	3600.
1.00	24.00	185.	3700.	100.	4000.
1.65	39.50	240.	4800.	130.	5200.
2.00	48.00	255.	5100.	160.	6400.
2.65	63.50	320.	6400.	200.	8000.
3.00	72.00	335.	6700.	225.	9000.
3.62	87.00	380.	7600.	235.	9400.
4.00	96.00	390.	7800.	250.	10000.
4.73	113.50	415.	8300.	265.	10600.
5.00	120.00	425.	8500.	290.	11600.

R = .9829; R**2 = .9661 R = .9737; R**2 = .9481

BOD = 6372.2 LOG HRS +(-4982.5) BOD = 9331.8 LOG HRS +(-8610.8)

22/6 1970	PIT 3	10A3	PIT 3	20B3
**********	*****	****	*****	****
TIME	SCALE	BOD	SCALE	BOD
DAYS HOURS	READING	(MG/L)	READING	(MG/L)
**** *****	*******	******	*******	******
0.65 15.50	175.	7000.	170.	8500.
1.00 24.00	260.	10400.	210.	10500.
1.65 39.50	325.	13000.	245.	12250.
2.00 48.00	335.	13400.	280.	14000.
2.65 63.50	395.	15800.	315.	15750.
3.00 72.00	410.	16400.	340.	17000.
3.62 87.00	440.	17600.	340.	17000.
4.00 96.00	445.	17800.	355.	17750.
4.73 113.50	475.	19000.	360.	18000.
5.00 120.00	475.	19000.	375.	18750.
	R = .9967; R**2 = .9935		R = .9919; R**2 = .9839	
	BOD = 13366.2 LOG HRS +(-8537.0)		BOD = 11765.5 LOG HRS +(-5715.5)	

22/6 1970	PIT 4	10A4	PIT 4	20B4
**********	*****	****	*****	****
TIME	SCALE	BOD	SCALE	BOD
DAYS HOURS	READING	(MG/L)	READING	(MG/L)
**** *****	*******	******	*******	******
0.65 15.50	160.	6400.	110.	5500.
1.00 24.00	245.	9800.	190.	9500.
1.65 39.50	300.	12000.	240.	12000.
2.00 48.00	315.	12600.	260.	13000.
2.65 63.50	370.	14800.	295.	14750.
3.00 72.00	410.	16400.	330.	16500.
3.62 87.00	440.	17600.	345.	17250.
4.00 96.00	450.	18000.	360.	18000.
4.73 113.50	475.	19000.	370.	18500.
5.00 120.00	500.	20000.	390.	19500.
	R = .9935; R**2 = .9871		R = .9958; R**2 = .9916	
	BOD = 14779.4 LOG HRS +(-11299.2)		BOD = 15067.1 LOG HRS +(-12014.5)	

28/6 1970	PIT 1	20A1	PIT 1	25B1
**********	*****	****	*****	****
TIME	SCALE	BOD	SCALE	BOD
DAYS HOURS	READING	(MG/L)	READING	(MG/L)
**** *****	*******	******	*******	******
0.69 16.50	65.	1300.	45.	1800.
1.02 24.50	80.	1600.	60.	2400.
1.71 41.00	140.	2800.	95.	3800.
1.92 46.00	155.	3100.	105.	4200.
2.10 50.50	170.	3400.	120.	4800.
2.69 64.50	215.	4300.	145.	5800.
3.04 73.00	225.	4500.	150.	6000.
3.69 88.50	280.	5600.	170.	6800.
4.04 97.00	290.	5800.	170.	6800.
4.74 113.75	335.	6700.	180.	7200.
5.00 120.00	345.	6900.	170.	6800.
	R = .9740; R**2 = .9486		R = .9869; R**2 = .9739	
	BOD = 6830.5 LOG HRS +(-7819.5)		BOD = 6732.5 LOG HRS +(-6701.9)	

29/6 1970	PIT 2	20A2	PIT 2	25B2
**********	*****	****	*****	****
TIME	SCALE	BOD	SCALE	BOD
DAYS HOURS	READING	(MG/L)	READING	(MG/L)
**** *****	*******	******	*******	******
0.69 16.50	175.	3500.	55.	2200.
1.02 24.50	200.	4000.	65.	2600.
1.71 41.00	255.	5100.	100.	4000.
1.92 46.00	265.	5300.	110.	4400.
2.10 50.50	275.	5500.	125.	5000.
2.69 64.50	310.	6200.	155.	6200.
3.04 73.00	340.	6800.	170.	6800.
3.69 88.50	375.	7500.	175.	7000.
4.04 97.00	405.	8100.	195.	7800.
4.74 113.75	455.	9100.	225.	9000.
5.00 120.00	500.	10000.	235.	9400.
	R = .9520; R**2 = .9062		R = .9732; R**2 = .9472	
	BOD = 7132.4 LOG HRS +(-6068.1)		BOD = 8588.8 LOG HRS +(-9236.1)	

29/6 1970	PIT 3	10A3	PIT 3	20B3
**********	*****	****	*****	****
TIME	SCALE	BOD	SCALE	BOD
DAYS HOURS	READING	(MG/L)	READING	(MG/L)
**** *****	*******	******	*******	******
0.69 16.50	110.	4400.	85.	4250.
1.02 24.50	210.	8400.	145.	7250.
1.71 41.00	265.	10600.	165.	8250.
1.92 46.00	275.	11000.	165.	3250.
2.10 50.50	285.	11400.	170.	8500.
2.69 64.50	325.	13000.	185.	9250.
3.04 73.00	330.	13200.	195.	9750.
3.69 88.50	380.	15200.	215.	10750.
4.04 97.00	375.	15000.	240.	12000.
4.74 113.75	400.	16000.	255.	12750.
5.00 120.00	420.	16800.	255.	12750.

R = .9916; R**2 = .9833 R = .9730; R**2 = .9466

BOD = 13207.4 LOG HRS +(-10932.8) BOD = 9079.9 LOG HRS +(-6521.8)

29/6 1970	PIT 4	10A4	PIT 4	20B4
**********	*****	****	*****	****
TIME	SCALE	BOD	SCALE	BOD
DAYS HOURS	READING	(MG/L)	READING	(MG/L)
**** *****	*******	******	*******	******
0.69 16.50	125.	5000.	75.	3750.
1.02 24.50	240.	9600.	135.	6750.
1.71 41.00	295.	11800.	200.	10000.
1.92 46.00	305.	12200.	205.	10250.
2.10 50.50	310.	12400.	210.	10500.
2.69 64.50	355.	14200.	230.	11500.
3.04 73.00	365.	14600.	240.	12000.
3.69 88.50	410.	16400.	260.	13000.
4.04 97.00	410.	16400.	270.	13500.
4.74 113.75	445.	17800.	285.	14250.
5.00 120.00	465.	18600.	285.	14250.

R = .9894; R**2 = .9790 R = .9912; R**2 = .9824

BOD = 14232.9 LOG HRS +(-11462.1) BOD = 11684.0 LOG HRS +(-9142.6)

6/7 1970	PIT 1	20A1	PIT 1	25B1
**********	*****	****	*****	****
TIME	SCALE	BOD	SCALE	BOD
DAYS HOURS	READING	(MG/L)	READING	(MG/L)
**** *****	*******	******	*******	******
0.69 16.50	40.	800.	45.	1800.
1.02 24.50	55.	1100.	75.	3000.
1.69 40.50	145.	2900.	135.	5400.
2.01 48.25	170.	3400.	135.	5400.
2.69 64.50	215.	4300.	170.	6800.
3.02 72.50	225.	4500.	165.	6600.
3.69 88.50	260.	5200.	165.	6600.
4.02 96.50	285.	5700.	160.	6400.
4.75 114.00	325.	6500.	175.	7000.
5.00 120.00	330.	6600.	175.	7000.
	R = .9896; R**2 = .9794		R = .9526; R**2 = .9075	
	BOD = 7031.5 LOG HRS +(-8300.1)		BOD = 5957.1 LOG HRS +(-4905.3)	

6/7 1970	PIT 2	20A2	PIT 2	25B2
**********	*****	****	*****	****
TIME	SCALE	BOD	SCALE	BOD
DAYS HOURS	READING	(MG/L)	READING	(MG/L)
**** *****	*******	******	*******	******
0.69 16.50	100.	2000.	55.	2200.
1.02 24.50	115.	2300.	60.	2400.
1.69 40.50	170.	3400.	110.	4400.
2.01 48.25	210.	4200.	130.	5200.
2.69 64.50	270.	5400.	165.	6600.
3.02 72.50	290.	5800.	160.	6400.
3.69 88.50	325.	6500.	170.	6800.
4.02 96.50	350.	7000.	155.	6200.
4.75 114.00	370.	7400.	175.	7000.
5.00 120.00	385.	7700.	175.	7000.
	R = .9829; R**2 = .9661		R = .9641; R**2 = .9296	
	BOD = 7121.1 LOG HRS +(-7388.2)		BOD = 6147.0 LOG HRS +(-5420.2)	

6/7 1970	PIT 3	10A3	PIT 3	20B3
**********	*****	****	*****	****
TIME	SCALE	BOD	SCALE	BOD
DAYS HOURS	READING	(MG/L)	READING	(MG/L)
**** *****	*******	******	*******	******
0.69 16.50	190.	7600.	200.	10000.
1.02 24.50	240.	9600.	245.	12250.
1.69 40.50	310.	12400.	295.	14750.
2.01 48.25	335.	13400.	310.	15500.
2.69 64.50	385.	15400.	360.	18000.
3.02 72.50	395.	15800.	360.	18000.
3.69 88.50	435.	17400.	385.	19250.
4.02 96.50	430.	17200.	375.	18750.
4.75 114.00	470.	18800.	410.	20500.
5.00 120.00	475.	19000.	400.	20000.

R = .9982; R**2 = .9964 R = .9933; R**2 = .9866

BOD = 13349.7 LOG HRS +(-8882.3) BOD = 12003.4 LOG HRS +(-4468.1)

6/7 1970	PIT 4	10A4	PIT 4	20B4
**********	*****	****	*****	****
TIME	SCALE	BOD	SCALE	BOD
DAYS HOURS	READING	(MG/L)	READING	(MG/L)
**** *****	*******	******	*******	******
0.69 16.50	160.	6400.	155.	7750.
1.02 24.50	280.	11200.	230.	11500.
1.69 40.50	300.	12000.	290.	14500.
2.01 48.25	335.	13400.	295.	14750.
2.69 64.50	375.	15000.	360.	18000.
3.02 72.50	385.	15400.	360.	18000.
3.69 88.50	415.	16600.	400.	20000.
4.02 96.50	415.	16600.	390.	19500.
4.75 114.00	450.	18000.	425.	21250.
5.00 120.00	465.	18600.	425.	21250.

R = .9830; R**2 = .9662 R = .9938; R**2 = .9876

BOD = 12576.3 LOG HRS +(-7859.2) BOD = 15377.4 LOG HRS +(-10468.1)

13/7 1970	PIT 1	20A1	PIT 1	25B1
**********	*****	****	*****	****
TIME	SCALE	BOD	SCALE	BOD
DAYS HOURS	READING	(MG/L)	READING	(MG/L)
**** *****	*******	******	*******	******
0.69 16.50	55.	1100.	35.	1400.
1.02 24.50	85.	1700.	45.	1800.
1.69 40.50	155.	3100.	125.	5000.
2.02 48.50	175.	3500.	130.	5200.
2.68 64.25	245.	4900.	180.	7200.
3.05 73.25	245.	4900.	190.	7600.
3.69 88.50	315.	6300.	240.	9600.
4.03 96.75	330.	6600.	265.	10600.
4.73 113.50	355.	7100.	260.	10400.
5.00 120.00	370.	7400.	265.	10600.
	R = .9844; R**2 = .9690		R = .9831; R**2 = .9665	
	BOD = 7652.9 LOG HRS +(-8839.2)		BOD = 11930.6 LOG HRS +(-14104.8)	

13/7 1970	PIT 2	20A2	PIT 2	25B2
**********	*****	****	*****	****
TIME	SCALE	BOD	SCALE	BOD
DAYS HOURS	READING	(MG/L)	READING	(MG/L)
**** *****	*******	******	*******	******
0.69 16.50	135.	2700.	70.	2800.
1.02 24.50	160.	3200.	70.	2800.
1.69 40.50	220.	4400.	120.	4800.
2.02 48.50	240.	4800.	140.	5600.
2.68 64.25	300.	6000.	190.	7600.
3.05 73.25	300.	6000.	195.	7800.
3.69 88.50	365.	7300.	240.	9600.
4.03 96.75	380.	7600.	265.	10600.
4.73 113.50	410.	8200.	270.	10800.
5.00 120.00	415.	8300.	275.	11000.
	R = .9811; R**2 = .9625		R = .9721; R**2 = .9451	
	BOD = 6886.7 LOG HRS +(-6297.6)		BOD = 10782.4 LOG HRS +(-11679.3)	

13/7 1970	PIT 3	10A3	PIT 3	20B3
**********	*****	****	*****	****
TIME	SCALE	BOD	SCALE	BOD
DAYS HOURS	READING	(MG/L)	READING	(MG/L)
**** *****	*******	******	*******	******
0.69 16.50	175.	7000.	140.	7000.
1.02 24.50	275.	11000.	205.	10250.
1.69 40.50	355.	14200.	270.	13500.
2.02 48.50	390.	15600.	290.	14500.
2.63 64.25	455.	18200.	355.	17750.
3.05 73.25	460.	18400.	370.	18500.
3.69 88.50	510.	20400.	410.	20500.
4.03 96.75	520.	20800.	420.	21000.
4.73 113.50	535.	21400.	525.	26250.
5.00 120.00	545.	21800.	520.	26000.
	R = .9965; R**2 = .9930		R = .9748; R**2 = .9503	
	BOD = 16984.3 LOG HRS +(-13079.1)		BOD = 21346.5 LOG HRS +(-20128.7)	

13/7 1970	PIT 4	10A4	PIT 4	20B4
**********	*****	****	*****	****
TIME	SCALE	BOD	SCALE	BOD
DAYS HOURS	READING	(MG/L)	READING	(MG/L)
**** *****	*******	******	*******	******
0.69 16.50	170.	6800.	130.	6500.
1.02 24.50	270.	10800.	210.	10500.
1.69 40.50	330.	13200.	265.	13250.
2.02 48.50	385.	15400.	280.	14000.
2.63 64.25	405.	16200.	345.	17250.
3.05 73.25	450.	18000.	355.	17750.
3.69 88.50	470.	18800.	410.	20500.
4.03 96.75	485.	19400.	425.	21250.
4.73 113.50	530.	21200.	415.	20750.
5.00 120.00	550.	22000.	420.	21000.
	R = .9939; R**2 = .9878		R = .9893; R**2 = .9787	
	BOD = 16489.6 LOG HRS +(-12906.5)		BOD = 17390.0 LOG HRS +(-14399.8)	

20/7 1970	PIT 1	20A1	PIT 1	25B1
**********	*****	****	*****	****
TIME	SCALE	BOD	SCALE	BOD
DAYS HOURS	READING	(MG/L)	READING	(MG/L)
**** *****	*******	******	*******	******
0.67 16.00	90.	1800.	50.	2000.
1.02 24.50	110.	2200.	65.	2600.
1.67 40.00	175.	3500.	135.	5400.
2.04 49.00	205.	4100.	150.	6000.
2.67 64.00	255.	5100.	185.	7400.
3.02 72.50	285.	5700.	200.	8000.
3.69 88.50	325.	6500.	215.	8600.
4.00 96.00	340.	6800.	215.	8600.
4.73 113.50	395.	7900.	250.	10000.
5.00 120.00	415.	8300.	250.	10000.
	R = .9754; R**2 = .9514		R = .9927; R**2 = .9854	
	BOD = 7585.4 LOG HRS +(-8172.0)		BOD = 9651.4 LOG HRS +(-10141.4)	

20/7 1970	PIT 2	20A2	PIT 2	25B2
**********	*****	****	*****	****
TIME	SCALE	BOD	SCALE	BOD
DAYS HOURS	READING	(MG/L)	READING	(MG/L)
**** *****	*******	******	*******	******
0.67 16.00	125.	2500.	60.	2400.
1.02 24.50	140.	2800.	70.	2800.
1.67 40.00	210.	4200.	165.	6600.
2.04 49.00	225.	4500.	195.	7800.
2.67 64.00	295.	5900.	275.	11000.
3.02 72.50	305.	6100.	290.	11600.
3.69 88.50	360.	7200.	320.	12800.
4.00 96.00	375.	7500.	335.	13400.
4.73 113.50	430.	8600.	365.	14600.
5.00 120.00	440.	8800.	370.	14800.
	R = .9718; R**2 = .9444		R = .9875; R**2 = .9752	
	BOD = 7545.9 LOG HRS +(-7482.4)		BOD = 15705.4 LOG HRS +(-17885.8)	

20/7 1970	PIT 3	10A3	PIT 3	20B3
**********	*****	****	*****	****
TIME	SCALE	BOD	SCALE	BOD
DAYS HOURS	READING	(MG/L)	READING	(MG/L)
**** *****	*******	******	*******	******
0.67 16.00	210.	8400.	195.	9750.
1.02 24.50	305.	12200.	240.	12000.
1.67 40.00	380.	15200.	310.	15500.
2.04 49.00	385.	15400.	330.	16500.
2.67 64.00	435.	17400.	405.	20250.
3.02 72.50	450.	18000.	400.	20000.
3.69 88.50	475.	19000.	410.	20500.
4.00 96.00	485.	19400.	415.	20750.
4.73 113.50	520.	20800.	435.	21750.
5.00 120.00	525.	21000.	440.	22000.

R = .9946; R**2 = .9892 R = .9869; R**2 = .9741

BOD = 13633.6 LOG HRS +(-7336.2)

BOD = 14543.2 LOG HRS +(-7718.5)

20/7 1970	PIT 4	10A4	PIT 4	20B4
**********	*****	****	*****	****
TIME	SCALE	BOD	SCALE	BOD
DAYS HOURS	READING	(MG/L)	READING	(MG/L)
**** *****	*******	******	*******	******
0.67 16.00	135.	5400.	140.	7000.
1.02 24.50	290.	11600.	200.	10000.
1.67 40.00	350.	14000.	270.	13500.
2.04 49.00	370.	14800.	280.	14000.
2.67 64.00	400.	16000.	330.	16500.
3.02 72.50	420.	16800.	335.	16750.
3.69 88.50	445.	17800.	365.	18250.
4.00 96.00	455.	18200.	375.	18750.
4.73 113.50	480.	19200.	405.	20250.
5.00 120.00	490.	19600.	410.	20500.

R = .9760; R**2 = .9525 R = .9982; R**2 = .9963

BOD = 14352.2 LOG HRS +(-9942.0)

BOD = 15214.5 LOG HRS +(-11251.1)

27/7 1970	PIT 1	20A1	PIT 1	25B1
**********	*****	****	*****	****
TIME	SCALE	BOD	SCALE	BOD
DAYS HOURS	READING	(MG/L)	READING	(MG/L)
**** *****	*******	******	*******	******
0.69 16.50	65.	1300.	45.	1800.
1.04 25.00	100.	2000.	55.	2200.
1.70 40.75	145.	2900.	110.	4400.
2.04 49.00	195.	3900.	155.	6200.
2.69 64.50	250.	5000.	195.	7800.
3.04 73.00	275.	5500.	215.	8600.
3.69 88.50	315.	6300.	230.	9200.
4.04 97.00	320.	6400.	250.	10000.
4.78 114.83	375.	7500.	265.	10600.
5.00 120.00	385.	7700.	260.	10400.
	R = .9827; R**2 = .9657		R = .9863; R**2 = .9728	
	BOD = 7688.4 LOG HRS +(-8728.9)		BOD = 11373.3 LOG HRS +(-12967.0)	

27/7 1970	PIT 2	20A2	PIT 2	25B2
**********	*****	****	*****	****
TIME	SCALE	BOD	SCALE	BOD
DAYS HOURS	READING	(MG/L)	READING	(MG/L)
**** *****	*******	******	*******	******
0.69 16.50	75.	1500.	45.	1800.
1.04 25.00	115.	2300.	65.	2600.
1.70 40.75	165.	3300.	120.	4800.
2.04 49.00	210.	4200.	150.	6000.
2.69 64.50	265.	5300.	185.	7400.
3.04 73.00	290.	5800.	205.	8200.
3.69 88.50	325.	6500.	230.	9200.
4.04 97.00	355.	7100.	255.	10200.
4.78 114.83	400.	8000.	280.	11200.
5.00 120.00	410.	8200.	280.	11200.
	R = .9833; R**2 = .9669		R = .9891; R**2 = .9783	
	BOD = 7998.7 LOG HRS +(-8907.0)		BOD = 11669.3 LOG HRS +(-13349.9)	

27/7 1970	PIT 3	10A3	PIT 3	20B3
**********	*****	****	*****	****
TIME	SCALE	BOD	SCALE	BOD
DAYS HOURS	READING	(MG/L)	READING	(MG/L)
**** *****	*******	******	*******	******
0.69 16.50	125.	5000.	140.	7000.
1.04 25.00	315.	12600.	240.	12000.
1.70 40.75	370.	14800.	295.	14750.
2.04 49.00	410.	16400.	320.	16000.
2.69 64.50	460.	18400.	370.	18500.
3.04 73.00	485.	19400.	390.	19500.
3.69 88.50	520.	20800.	430.	21500.
4.04 97.00	525.	21000.	445.	22250.
4.78 114.83	565.	22600.	460.	23000.
5.00 120.00	575.	23000.	460.	23000.
	R = .9820; R**2 = .9644		R = .9955; R**2 = .9910	
	BOD = 18796.8 LOG HRS +(-15798.1)		BOD = 18387.7 LOG HRS +(-14725.7)	

27/7 1970	PIT 4	10A4	PIT 4	20B4
**********	*****	****	*****	****
TIME	SCALE	BOD	SCALE	BOD
DAYS HOURS	READING	(MG/L)	READING	(MG/L)
**** *****	*******	******	*******	******
0.69 16.50	70.	2800.	60.	3000.
1.04 25.00	215.	8600.	155.	7750.
1.70 40.75	350.	14000.	260.	13000.
2.04 49.00	385.	15400.	280.	14000.
2.69 64.50	430.	17200.	315.	15750.
3.04 73.00	455.	18200.	320.	16000.
3.69 88.50	490.	19600.	355.	17750.
4.04 97.00	490.	19600.	365.	18250.
4.78 114.83	545.	21800.	375.	18750.
5.00 120.00	545.	21800.	380.	19000.
	R = .9888; R**2 = .9778		R = .9847; R**2 = .9696	
	BOD = 20915.3 LOG HRS +(-21039.7)		BOD = 17935.4 LOG HRS +(-17351.7)	

2/8 1970	PIT 1	20A1	PIT 1	25F1
**********	*****	****	*****	****
TIME	SCALE	BOD	SCALE	BOD
DAYS HOURS	READING	(MG/L)	READING	(MG/L)
**** *****	*******	******	*******	******
0.75 18.00	35.	700.	10.	400.
1.03 24.75	60.	1200.	30.	1200.
1.70 40.75	160.	3200.	115.	4600.
2.06 49.50	155.	3100.	130.	5200.
2.70 64.75	230.	4600.	175.	7000.
3.02 72.50	240.	4800.	185.	7400.
3.70 88.75	310.	6200.	215.	8600.
4.02 96.50	310.	6200.	225.	9000.
4.70 112.75	315.	6300.	220.	8800.
5.09 122.15	325.	6500.	225.	9000.
	R = .9876; R**2 = .9753		R = .9894; R**2 = .9788	
	BOD = 7584.7 LOG HRS +(-9142.5)		BOD = 11323.2 LOG HRS +(-13918.5)	

2/8 1970	PIT 2	20A2	PIT 2	25B2
**********	*****	****	*****	****
TIME	SCALE	BOD	SCALE	BOD
DAYS HOURS	READING	(MG/L)	READING	(MG/L)
**** *****	*******	******	*******	******
0.75 18.00	75.	1500.	45.	1800.
1.03 24.75	95.	1900.	60.	2400.
1.70 40.75	180.	3600.	135.	5400.
2.06 49.50	180.	3600.	155.	6200.
2.70 64.75	250.	5000.	205.	8200.
3.02 72.50	265.	5300.	210.	8400.
3.70 88.75	335.	6700.	260.	10400.
4.02 96.50	340.	6800.	265.	10600.
4.70 112.75	345.	6900.	270.	10800.
5.09 122.15	360.	7200.	285.	11400.
	R = .9849; R**2 = .9700		R = .9929; R**2 = .9858	
	BOD = 7436.5 LOG HRS +(-8310.3)		BOD = 12396.7 LOG HRS +(-14378.2)	

2/8 1970	PIT 3	10A3	PIT 3	20B3
**********	*****	****	*****	****

TIME		SCALE	BOD	SCALE	BOD
DAYS	HOURS	READING	(MG/L)	READING	(MG/L)
****	*****	*******	******	*******	******
0.75	18.00	215.	3600.	195.	9750.
1.03	24.75	315.	12600.	260.	13000.
1.70	40.75	380.	15200.	340.	17000.
2.06	49.50	380.	15200.	370.	18500.
2.70	64.75	430.	17200.	430.	21500.
3.02	72.50	440.	17600.	430.	21500.
3.70	88.75	485.	19400.	460.	23000.
4.02	96.50	485.	19400.	460.	23000.
4.70	112.75	490.	19600.	460.	23000.
5.00	122.15	495.	19800.	470.	23500.

R = .9811; R**2 = .9625 R = .9835; R**2 = .9673

BOD = 12795.1 LOG HRS +(-6183.2) BOD = 16770.9 LOG HRS +(-10304.3)

2/8 1970	PIT 4	10A4	PIT 4	20B4
**********	*****	****	*****	****

TIME		SCALE	BOD	SCALE	BOD
DAYS	HOURS	READING	(MG/L)	READING	(MG/L)
****	*****	*******	******	*******	******
0.75	18.00	155.	6200.	135.	6750.
1.03	24.75	285.	11400.	215.	10750.
1.70	40.75	360.	14400.	285.	14250.
2.06	49.50	360.	14400.	300.	15000.
2.70	64.75	410.	16400.	350.	17500.
3.02	72.50	420.	16800.	350.	17500.
3.70	88.75	465.	18600.	385.	19250.
4.02	96.50	470.	18800.	390.	19500.
4.70	112.75	470.	18800.	395.	19750.
5.00	122.15	475.	19000.	395.	19750.

R = .9703; R**2 = .9416 R = .9846; R**2 = .9695

BOD = 14235.9 LOG HRS +(-9713.0) BOD = 15401.2 LOG HRS +(-11255.3)

8/8 1970	PIT 1	20A1	PIT 1	25B1
**********	*****	****	*****	****

TIME		SCALE	BOD	SCALE	BOD
DAYS	HOURS	READING	(MG/L)	READING	(MG/L)
****	*****	*******	******	*******	******
0.75	18.00	65.	1300.	NO DATA	
1.02	24.50	80.	1600.	OBTAINED	
1.70	40.75	155.	3100.		
2.06	49.50	165.	3300.		
2.71	65.00	215.	4300.		
3.05	73.25	220.	4400.		
3.70	88.75	270.	5400.		
3.97	95.25	275.	5500.		
4.71	113.00	345.	6900.		
5.09	122.25	340.	6800.		
5.69	136.50	385.	7700.		

R = .9752; R**2 = .9510

BOD = 7192.8 LOG HRS
+(-8393.4)

8/8 1970	PIT 2	20A2	PIT 2	25B2
**********	*****	****	*****	****

TIME		SCALE	BOD	SCALE	BOD
DAYS	HOURS	READING	(MG/L)	READING	(MG/L)
****	*****	*******	******	*******	******
0.75	18.00	55.	1100.	35.	1400.
1.02	24.50	75.	1500.	55.	2200.
1.70	40.75	165.	3300.	110.	4400.
2.06	49.50	185.	3700.	130.	5200.
2.71	65.00	245.	4900.	190.	7600.
3.05	73.25	260.	5200.	200.	8000.
3.70	88.75	315.	6300.	245.	9800.
3.97	95.25	340.	6800.	260.	10400.
4.71	113.00	410.	8200.	290.	11600.
5.09	122.25	415.	8300.	305.	12200.
5.69	136.50	460.	9200.	330.	13200.

R = .9787; R**2 = .9579

BOD = 9285.1 LOG HRS
+(-11419.8)

R = .9856; R**2 = .9715

BOD = 13875.1 LOG HRS
+(-17194.1)

8/8 1970	PIT 3	10A3	PIT 3	20B3
**********	*****	****	*****	****
TIME	SCALE	BOD	SCALE	BOD
DAYS HOURS	READING	(MG/L)	READING	(MG/L)
**** *****	*******	******	*******	******
0.75 18.00	200.	8000.	180.	9000.
1.02 24.50	310.	12400.	255.	12750.
1.70 40.75	375.	15000.	330.	16500.
2.06 49.50	395.	15800.	350.	17500.
2.71 65.00	445.	17800.	425.	21250.
3.05 73.25	450.	18000.	435.	21750.
3.70 88.75	480.	19200.	475.	23750.
3.97 95.25	490.	19600.	485.	24250.
4.71 113.00	530.	21200.	510.	25500.
5.09 122.25	530.	21200.	520.	26000.
5.69 136.50	550.	22000.	535.	26750.

R = .9897; R**2 = .9794 R = .9972; R**2 = .9943

BOD = 14583.3 LOG HRS +(-8999.0) BOD = 20136.0 LOG HRS +(-15844.0)

8/8 1970	PIT 4	10A4	PIT 4	20B4
**********	*****	****	*****	****
TIME	SCALE	BOD	SCALE	BOD
DAYS HOURS	READING	(MG/L)	READING	(MG/L)
**** *****	*******	******	*******	******
0.75 18.00	145.	5800.	155.	7750.
1.02 24.50	270.	10800.	230.	11500.
1.70 40.75	355.	14200.	285.	14250.
2.06 49.50	375.	15000.	305.	15250.
2.71 65.00	420.	16800.	345.	17250.
3.05 73.25	425.	17000.	360.	18000.
3.70 88.75	465.	18600.	400.	20000.
3.97 95.25	475.	19000.	415.	20750.
4.71 113.00	510.	20400.	440.	22000.
5.09 122.25	510.	20400.	445.	22250.
5.69 136.50	530.	21200.	460.	23000.

R = .9861; R**2 = .9723 R = .9957; R**2 = .9915

BOD = 15966.3 LOG HRS +(-12491.1) BOD = 16822.9 LOG HRS +(-12871.6)

APPENDIX IV

VALUES OF k (RATE CONSTANT) AND L (ULTIMATE BOD).

The following data give the various k and L values determined by the computer program in Appendix VIII. The means and standard deviations (SD) are given for k and L.

The three sections of this appendix are:

(A) uncorrected rate constants (k);

(B) corrected rate constants (k_{20}) using the temperature correction as follows (18,56,68):

$$k_{20} = \frac{k}{1.047^{(T-20)}}$$

where k = uncorrected k from (A),

T = mean 5-day BOD temperature (Appendix III),

k_{20} = k value corrected to 20°C;

(C) ultimate BOD.

The following symbols are used to identify the various methods of determination of k and L:

(1) LD - log-difference method,

(2) S - slope method, and

(3) MM - method of moments.

The symbols, A1 to B4, signify the dilution used for a given pit and Hach BOD apparatus as given in Section 4.3.2.3.

The following superscripts are used to explain the presented values:

(a) the 1 to 5 day sequence used unless otherwise specified,

(b) no BOD data obtained,

(c) program unable to handle data for this method,

(d) program data outside the range of graphs as given by Moore et al. (44),

(e) the 1-7 day sequence used,

(f) the 1-3 day sequence used, and

(g) value extremely out of proportion with others in the same column and row and, therefore, was not included in determining the mean and standard deviation.

SECTION A: UNCORRECTED RATE CONSTANTS.

k (days^{-1}) for Pit 1

Test day	A1 LD	A1 S	A1 MM[a]	B1 LD	B1 S	B1 MM[a]
79	——[b]	——[b]	——[b]	0.066	0.079	0.063[e]
86	——[c]	0.016	——[d]	0.041	0.067	——[d]
94	0.010	0.055	——[d]	0.032	0.063	——[d]
100	0.022	0.059	——[d]	0.033	0.063	——[d]
107	0.054	0.072	0.056[e]	——[c]	0.030	——[d]
114	0.109	0.110	0.080	0.178	0.207	0.200
121	0.138	0.142	0.124	0.184	0.220	0.212
127	0.125	0.127	0.104	0.191	0.236	0.228
133	0.181	0.213	0.206	0.237	0.380	0.330
142	0.177	0.205	0.196	0.142	0.147	0.130
149	0.130	0.132	0.110	0.201	0.261	0.250
156	0.154	0.164	0.151	0.151	0.160	0.147
163	0.115	0.116	0.089	0.158	0.171	0.159
170	0.101	0.103	0.069	0.190	0.234	0.336
177	0.111	0.112	0.083	0.100	0.102	0.067
184	0.137	0.141	0.122	0.144	0.150	0.134
191	0.119	0.120	0.094	0.117	0.118	0.091
197	0.089	0.094	0.080[e]	0.077	0.085	0.070[e]
203	0.107	0.108	0.077	——[b]	——[b]	——[b]
Mean	0.110	0.116	0.109	0.132	0.154	0.164
SD	0.047	0.049	0.044	0.064	0.090	0.080

Gross Mean 0.132 days^{-1}

SD 0.065 days^{-1}

k (days^{-1}) for Pit 2

Test day	A2 LD	A2 S	A2 MM[a]	B2 LD	B2 S	B2 MM[a]
79	0.017	0.058	___[d]	0.125	0.126	0.103
86	0.026	0.060	___[d]	0.054	0.073	___[d]
94	0.089	0.094	0.080[e]	0.028	0.062	___[d]
100	0.102	0.103	0.070	0.094	0.098	0.084[e]
107	0.143	0.148	0.132	___[c]	0.029	___[d]
114	___[c]	0.050	___[d]	0.194	0.245	0.236
121	0.144	0.150	0.134	0.125	0.126	0.104
127	0.139	0.144	0.126	0.199	0.255	0.245
133	0.111	0.112	0.082	0.110	0.110	0.080
142	0.211	0.289	0.274	0.125	0.126	0.104
149	0.132	0.135	0.115	0.159	0.172	0.160
156	0.196	0.249	0.240	0.173	0.197	0.190
163	0.186	0.224	0.216	0.138	0.142	0.124
170	0.148	0.155	0.141	0.180	0.212	0.206
177	0.174	0.200	0.192	0.135	0.139	0.120
184	0.159	0.172	0.160	0.117	0.118	0.092
191	0.126	0.128	0.103	0.116	0.116	0.089
197	0.125	0.126	0.103	0.110	0.110	0.081
203	0.076	0.085	0.070[e]	0.071	0.082	0.066[e]
Mean	0.128	0.141	0.140	0.125	0.133	0.130
SD	0.052	0.064	0.062	0.046	0.060	0.058

Gross Mean 0.133 days^{-1}

SD 0.056 days^{-1}

k (days^{-1}) values for Pit 3

Test day	A3 LD	A3 S	A3 MM[a]	B3 LD	B3 S	B3 MM[a]
79	0.301	0.764[g]	——[d]	0.313	0.873[g]	——[d]
86	0.154	0.165	0.152	0.186	0.225	0.216
94	0.161	0.177	0.162	0.203	0.266	0.255
100	0.165	0.183	0.172	0.179	0.209	0.203
107	0.160	0.175	0.162	0.146	0.152	0.138
114	0.198	0.253	0.242	0.220	0.317	0.298
121	0.199	0.257	0.247	0.229	0.350	0.320
127	0.177	0.205	0.196	0.224	0.333	0.308
133	0.202	0.265	0.254	0.229	0.348	0.322
142	0.237	0.379	0.338	0.234	0.368	0.331
149	0.187	0.227	0.219	0.174	0.199	0.190
156	0.215	0.302	0.284	0.231	0.358	0.326
163	0.189	0.232	0.223	0.205	0.272	0.260
170	0.212	0.292	0.276	0.242	0.399	0.450[f]
177	0.198	0.253	0.242	0.169	0.190	0.181
184	0.226	0.338	0.313	0.227	0.341	0.314
191	0.187	0.228	0.219	0.194	0.242	0.233
197	0.231	0.358	0.326	0.218	0.310	0.292
203	0.217	0.309	0.290	0.196	0.247	0.238
Mean	0.201	0.255	0.240	0.211	0.285	0.271
SD	0.034	0.064	0.057	0.036	0.072	0.073

Gross Mean 0.243 days^{-1}

SD 0.064 days^{-1}

k (days^{-1}) values for Pit 4

Test day	A4 LD	A4 S	A4 MM[a]	B4 LD	B4 S	B4 MM[a]
79	0.279	0.600[g]	—[d]	0.234	0.370	0.334
86	0.161	0.176	0.164	0.156	0.167	0.155
94	0.160	0.174	0.163	0.199	0.256	0.246
100	0.173	0.197	0.190	0.209	0.283	0.268
107	0.162	0.178	0.166	0.154	0.164	0.152
114	0.162	0.178	0.168	0.236	0.375	0.338
121	0.193	0.240	0.230	0.231	0.358	0.327
127	0.181	0.214	0.206	0.203	0.267	0.254
133	0.189	0.232	0.223	0.207	0.278	0.264
142	0.248	0.428	0.478[f]	0.190	0.233	0.225
149	0.208	0.281	0.268	0.201	0.262	0.250
156	0.199	0.255	0.246	0.194	0.243	0.234
163	0.193	0.240	0.231	0.190	0.233	0.224
170	0.216	0.306	0.288	0.210	0.286	0.272
177	0.196	0.249	0.240	0.189	0.232	0.223
184	0.208	0.282	0.268	0.202	0.265	0.252
191	0.155	0.167	0.156	0.164	0.181	0.170
197	0.210	0.286	0.271	0.203	0.268	0.256
203	0.196	0.249	0.239	0.199	0.255	0.245
Mean	0.194	0.241	0.233	0.198	0.262	0.247
SD	0.031	0.064	0.o74	0.023	0.059	0.052

Gross Mean 0.229 days^{-1}

SD 0.058 days^{-1}

SECTION B: CORRECTED RATE CONSTANTS

k_{20} ($days^{-1}$) values for Pit 1

Test day	A1 LD	A1 S	A1 MM[a]	B1 LD	B1 S	B1 MM[a]
79	___[b]	___[b]	___[b]	0.056	0.067	0.054[e]
86	___[c]	0.013	___[d]	0.035	0.056	___[d]
94	0.009	0.049	___[d]	0.028	0.056	___[d]
100	0.019	0.052	___[d]	0.029	0.055	___[d]
107	0.046	0.062	0.048[e]	___[c]	0.025	___[d]
114	0.094	0.095	0.069	0.154	0.179	0.173
121	0.117	0.121	0.106	0.158	0.188	0.180
127	0.112	0.114	0.094	0.172	0.212	0.205
133	0.140	0.166	0.160	0.184	0.296	0.256
142	0.157	0.182	0.174	0.126	0.130	0.115
149	0.111	0.113	0.094	0.173	0.224	0.215
156	0.122	0.129	0.119	0.120	0.127	0.116
163	0.097	0.098	0.075	-.133	0.143	0.134
170	0.076	0.078	0.052	0.144	0.177	0.171
177	0.084	0.085	0.063	0.076	0.078	0.051
184	0.113	0.116	0.100	0.119	0.124	0.110
191	0.102	0.103	0.081	0.101	0.102	0.078
197	0.066	0.069	0.059[e]	0.056	0.063	0.051[e]
203	0.085	0.086	0.061	___[b]	___[b]	___[b]
Mean	0.091	0.096	0.090	0.109	0.128	0.136
SD	0.039	0.041	0.036	0.053	0.073	0.065

Gross Mean 0.108 $days^{-1}$

SD 0.055 $days^{-1}$

k_{20} ($days^{-1}$) values for Pit 2

Test day	A2 LD	A2 S	A2 MM[a]	B2 LD	B2 S	B2 MM[a]
79	0.014	0.049	___[d]	0.106	0.107	0.088
86	0.022	0.051	___[d]	0.046	0.061	___[d]
94	0.079	0.083	0.071[e]	0.025	0.055	___[d]
100	0.088	0.090	0.061	0.082	0.085	0.073[e]
114	___[c]	0.043	___[d]	0.068	0.211	0.204
121	0.123	0.128	0.114	0.107	0.108	0.088
127	0.125	0.129	0.113	0.179	0.230	0.220
133	0.086	0.087	0.064	0.085	0.086	0.062
142	0.187	0.256	0.243	0.111	0.112	0.092
149	0.114	0.116	0.099	0.136	0.148	0.137
156	0.155	0.197	0.190	0.137	0.156	0.150
163	0.156	0.188	0.181	0.116	0.119	0.104
170	0.112	0.117	0.106	0.136	0.160	0.156
177	0.132	0.152	0.146	0.102	0.105	0.091
184	0.131	0.142	0.132	0.097	0.098	0.076
191	0.109	0.110	0.089	0.100	0.100	0.077
197	0.092	0.093	0.076	0.080	0.081	0.060
203	0.061	0.067	0.056[e]	0.056	0.065	0.052[e]
Mean	0.106	0.117	0.116	0.104	0.111	0.108
SD	0.044	0.054	0.051	0.039	0.052	0.050

Gross Mean 0.110 $days^{-1}$

SD 0.048 $days^{-1}$

k_{20} ($days^{-1}$) values for Pit 3

Test day	A3 LD	A3 S	A3 MM[a]	B3 LD	B3 S	B3 MM[a]
79	0.256	0.650[g]	——[d]	0.267	0.743[g]	——[d]
86	0.130	0.139	0.128	0.157	0.190	0.182
94	0.144	0.157	0.144	0.181	0.237	0.227
100	0.144	0.157	0.144	0.181	0.237	0.227
107	0.137	0.150	0.138	0.125	0.130	0.118
114	0.171	0.218	0.209	0.190	0.274	0.257
121	0.170	0.219	0.210	0.195	0.292	0.272
127	0.159	0.184	0.176	0.202	0.300	0.277
133	0.157	0.206	0.197	0.178	0.270	0.250
142	0.210	0.336	0.300	0.208	0.326	0.294
149	0.161	0.195	0.188	0.149	0.171	0.163
156	0.170	0.238	0.224	0.183	0.283	0.258
163	0.159	0.195	0.187	0.172	0.229	0.218
170	0.160	0.220	0.209	0.182	0.302	0.340[f]
177	0.150	0.092	0.184	0.128	0.144	0.137
184	0.186	0.279	0.258	0.187	0.281	0.259
191	0.162	0.196	0.189	0.167	0.209	0.201
197	0.170	0.264	0.240	0.160	0.228	0.214
203	0.173	0.246	0.230	0.155	0.196	0.189
Mean	0.167	0.210	0.198	0.176	0.236	0.224
SD	0.028	0.049	0.044	0.031	0.058	0.056

Gross Mean 0.201 $days^{-1}$

SD 0.051 $days^{-1}$

k_{20}(days^{-1}) values for Pit 4

Test day	A4 LD	A4 S	A4 MM[a]	B4 LD	B4 S	B4 MM[a]
79	0.238	0.511[g]	——[d]	0.200	0.315	0.284
86	0.136	0.148	0.138	0.131	0.141	0.131
94	0.143	0.155	0.145	0.178	0.228	0.219
100	0.151	0.172	0.166	0.182	0.246	0.233
107	0.139	0.152	0.142	0.131	0.140	0.130
114	0.140	0.154	0.145	0.204	0.323	0.292
121	0.164	0.205	0.196	0.197	0.305	0.278
127	0.163	0.193	0.185	0.183	0.240	0.229
133	0.147	0.180	0.173	0.161	0.216	0.205
142	0.220	0.380	0.424[f]	0.168	0.207	0.200
149	0.179	0.242	0.230	0.173	0.225	0.215
156	0.157	0.202	0.195	0.154	0.192	0.185
163	0.162	0.202	0.194	0.159	0.196	0.188
170	0.164	0.232	0.218	0.158	0.216	0.206
177	0.149	0.189	0.182	0.144	0.176	0.169
184	0.172	0.232	0.221	0.167	0.218	0.208
191	0.134	0.144	0.135	0.142	0.156	0.147
197	0.154	0.210	0.199	0.150	0.197	0.188
203	0.156	0.198	0.190	0.158	0.203	0.195
Mean	0.161	0.199	0.193	0.165	0.218	0.205
SD	0.030	0.054	0.064	0.021	0.052	0.046

Gross Mean 0.190 days^{-1}

SD 0.050 days^{-1}

SECTION C: ULTIMATE BOD

L (mg/l) vlaues for Pit 1

Test day	A1 LD	A1 S	A1 MM[a]	B1 LD	B1 S	B1 MM[a]
79	——[b]	——[b]	——[b]	5790	5340	5800[e]
86	——[c]	16000	——[d]	6910	5050	——[d]
94	46100[g]	10600	——[d]	13500	8240	——[d]
100	18100	8340	——[d]	13300	8450	——[d]
107	9460	8020	8900[e]	——[c]	22300	——[d]
114	7820	7980	9600	2320	2200	2200
121	7930	7950	8400	5000	4700	4700
127	5980	6070	6700	5060	4720	4700
133	5180	4900	4900	4130	3690	3700
142	6970	6630	6700	11500	11400	12000
149	8720	8820	9600	7040	6490	6500
156	8530	8380	8600	11600	11400	11700
163	8700	8870	10200	8720	8520	8700
170	9230	9390	12100	8500	7940	8000
177	9800	10000	12000	15700	16000	20600
184	9570	9600	10200	12200	12200	12800
191	9750	9930	11300	14400	14700	17000
197	10400	10400	10900[e]	16600	16100	17200[e]
203	9300	9490	11600	——[b]	——[b]	——[b]
Mean	9100	9000	9400	9500	9400	9700
SD	2800	2300	2100	4400	5300	5700

Gross Mean 9300 mg/l

SD 3900 mg/l

L (mg/l) values for Pit 2

Test day	A2 LD	A2 S	A2 MM[a]	B2 LD	B2 S	B2 MM[a]
79	18500	6950	___[d]	4410	4480	4900
86	24600[g]	12900	___[d]	11400	9680	___[d]
94	8190	8200	8600[e]	19900	11200	___[d]
100	7350	7480	9500	9570	9680	10100[e]
107	6240	6220	6500	___[c]	22200	___[d]
114	___[c]	11000	___[d]	2990	2780	2800
121	7300	7270	7600	12200	12400	13700
127	7910	7920	8300	5250	4850	4900
133	8140	8310	9900	10900	11200	13400
142	5590	5100	5100	15200	15400	17000
149	7530	7590	8100	12500	12200	12500
156	9330	8650	8700	12600	12000	12100
163	10000	9400	9400	10800	10900	11500
170	9070	8990	9300	8460	8010	8000
177	9300	8880	9000	13600	13700	14600
184	9790	9550	9800	19900	20300	23200
191	10100	10200	11400	14800	15200	17400
197	9380	9520	10500	15900	16300	19400
203	13600	13200	14000[e]	21200	20100	21700[e]
Mean	9200	8800	9100	12300	12200	13000
SD	3900	2000	2000	5200	5300	6000

Gross Mean 10800 mg/l

SD 4500 mg/l

L (mg/l) values for Pit 3

Test day	A3 LD	A3 S	A3 MM[a]	B3 LD	B3 S	B3 MM[a]
79	8260	7280	—[d]	7530	6640	—[d]
86	17100	16800	17200	12400	11600	11700
94	17000	16500	16800	14400	13300	13300
100	19100	18400	18700	18100	17200	17300
107	15600	15200	15400	18200	18000	18600
114	16700	15500	15500	16100	14500	14600
121	18900	17500	17500	15000	13500	13600
127	20700	19700	19900	17100	15400	15600
133	19700	18100	18100	19500	17500	17600
142	19300	17200	17400	25000	22300	22800
149	20400	19200	19200	22500	22300	22800
156	21400	19400	19500	20600	18500	18600
163	18800	17600	17700	13800	12700	12700
170	21000	19200	19200	22400	20000	18400[f]
177	25000	32300	23200	28400	27300	27600
184	23200	20900	21000	24800	22300	22500
191	26500	24900	24900	26600	24800	24800
197	22500	20200	20300	27200	24700	24800
203	23600	21400	21500	29400	27300	27400
Mean	19700	18300	19000	20000	18400	19100
SD	4000	3600	6200	6000	5600	5100

Gross Mean 19100 mg/l

SD 4600 mg/l

L (mg/l) values for Pit 4

Test day	A4 LD	A4 S	A4 MM[a]	B4 LD	B4 S	B4 MM[a]
79	8530	7510	___[d]	10400	9340	9400
86	14800	14400	14700	14500	14200	14600
94	16400	16000	16300	12500	11600	11600
100	15200	14600	14700	13900	12700	12800
107	17800	17300	17500	17400	17100	17500
114	18100	17600	17900	18400	16400	16600
121	17100	15900	16000	13700	12300	12400
127	19300	18300	18400	14500	13400	13400
133	19800	18500	18600	16100	14800	15900
142	17400	15500	14300[f]	22900	21100	21200
156	21900	20200	20300	21800	20300	20400
163	20500	19100	19200	16600	15600	15600
170	20300	18400	18500	24000	21900	22000
177	24100	22400	22400	24700	23100	23200
184	22200	20300	20400	22900	21100	21200
191	27000	26400	27100	23600	22800	23200
197	22200	20200	20300	23300	21400	21500
203	23400	21700	21700	24900	23000	23100
Mean	19300	18000	18700	18900	17600	17700
SD	4100	3900	3100	4800	4500	4500

Gross Mean 18400 mg/l

SD 4100 mg/l

APPENDIX V

DATA: PIT TEMPERATURE AND DEPTH

The following appendix shows the temperature (temp) and depth of each pit on the day of sampling for the standard engineering test samples. The temperature was measured to the nearest 0.5^{o}C and the depth was measured to the nearest inch.

Test day	Pit 1 Temp °C	Pit 1 Depth ft-in	Pit 2 Temp °C	Pit 2 Depth ft-in
11		2-0		1-11
79		2-2		2-3
86		2-4		2-5
94		2-6		2-6
100	14.0	2-7	15.0	2-7
107		2-8		2-9
114		2-9		2-8
121	14.5	2-8	15.0	2-7
127	14.0	2-8	14.5	2-7
133	15.0	2-6	14.5	2-5
142	18.5	2-4	18.5	2-2
149	20.0	2-8	21.0	2-4
156	19.5	2-8	18.5	2-4
163	17.5	2-7	17.5	2-5
170	22.0	2-8	21.5	2-6
177	20.5	2-8	20.0	2-5
184	20.0	2-9	20.0	2-5
191	16.5	2-9	15.0	2-4
197	17.0	2-8	17.5	2-5
203	19.0	2-8	18.5	2-6
209	16.0	2-7	15.0	2-4

Test day	Pit 3 Temp °C	Pit 3 Depth ft-in	Pit 4 Temp °C	Pit 4 Depth ft-in
11		2-0		2-1
79		2-6		2-7
86		2-8		2-8
94		2-9		2-9
100	13.0	2-10	13.0	2-10
107		2-11		2-11
114		3-0		3-0
121	15.0	3-1	15.5	3-1
127	14.0	3-2	13.0	3-2
133	13.5	3-3	14.0	3-4
142	16.0	3-5	16.0	3-5
149	17.0	3-6	17.0	3-7
156	16.5	3-7	16.0	3-8
163	17.0	3-8	16.5	3-9
170	19.0	3-9	18.5	3-10
177	19.0	3-10	18.0	3-11
184	18.5	3-11	18.0	4-0
191	17.0	3-11	17.0	4-0
197	17.0	3-10	17.0	3-11
203	17.0	3-9	17.0	3-11
209	16.0	3-9	16.0	3-10

APPENDIX VI

DATA: LAG PERIODS

The following table shows the lag periods, in hours, as computed from the "slope" method used in the Fortran program (Appendix VIII). The samples that were seeded over the test period are marked with an asterisk (*).

Test Day	Pit 1		Pit 2		Pit 3		Pit 4	
	A	B	A	B	A	B	A	B
79	-	6.0	8.2	3.0	4.4	5.2	3.0	1.2
86	15.4*	7.2	7.9*	6.6	1.8*	1.0	1.5*	1.7
94	8.5*	7.6	4.8	7.8*	1.5*	0.8	1.6	0.9*
100	8.0	7.6*	4.2*	4.5	1.4	1.1*	1.2*	0.8
107	6.6	12.6*	2.2	12.6*	1.6	2.1*	1.5	1.8*
114	3.8	1.1	9.3	0.9	0.9	0.9	1.5	1.2
121	2.4	1.0	2.1	3.0	0.9	1.1	0.9	1.1
127	3.0	0.9	2.3	0.9	1.1	1.0	1.0	0.8
133	1.1	1.3	3.7	3.8	0.8	1.1	0.9	0.8
142	1.1	2.2	0.9	3.0	1.2	1.2	1.6	0.9
149	2.8	0.8	2.6	1.6	1.0	1.2	0.8	0.8
156	1.8	1.9	0.9	1.2	0.9	1.1	0.9	0.9
163	3.4	1.6	1.0	2.4	0.9	0.8	0.9	0.9
170	4.2	0.9	2.0	1.1	0.9	1.4	0.9	0.9
177	3.6	4.2	1.2	2.5	0.9	1.3	0.9	0.9
184	2.4	2.1	1.6	3.4	1.0	1.0	0.8	0.8
191	3.3	3.4	2.9	3.4	1.0	0.9	1.7	1.4
197	4.8	5.4	3.0	3.7	1.1	0.9	0.9	0.8
203	3.9	-	5.5	5.8	0.9	0.9	0.9	0.9

APPENDIX VII

THE OXYGEN DEMAND INDEX (ODI) TEST

This test is a modification of the dichromate chemical oxygen demand (COD) test and is well suited for a semi-skilled operator. The procedure, adopted from Simpson (60), used standard COD reagents.

Reagents

1. Potassium dichromate ($K_2Cr_2O_7$) - reagent grade.
2. Mercuric sulphate ($HgSO_4$) - reagent grade crystals or powder.
3. Silver sulphate (Ag_2SO_4) - reagent powder.
4. Sulphuric acid (H_2SO_4) - concentrated - reagent grade.
5. Dextrose (glucose) crystal - reagent or bacterial grade (anhydrous).

Solutions

1. Standard 0.25N dichromate solution - 12.259g $K_2Cr_2O_7$ (dried at 103°C for 2 hours) dissolved in distilled water and diluted to 1000 ml.
2. Sulphuric acid - silver sulphate reagent - Add 22 g Ag_2SO_4 to a standard 9 lb. bottle of concentrated H_2SO_4. Invert occasionally to aid dissolution. One to two days may be required. (Note 1)
3. Standard glucose solution for calibration curve - Dissolve 0.600 g glucose (dried at 103°C for 1 hour) in distilled water and dilute to 1000 ml. This solution should have a BOD of 448 $\pm$ 20 mg/l (80); therefore, one ml of this solution diluted to 5 ml has an ODI of 90 mg/l based on ODI tests.

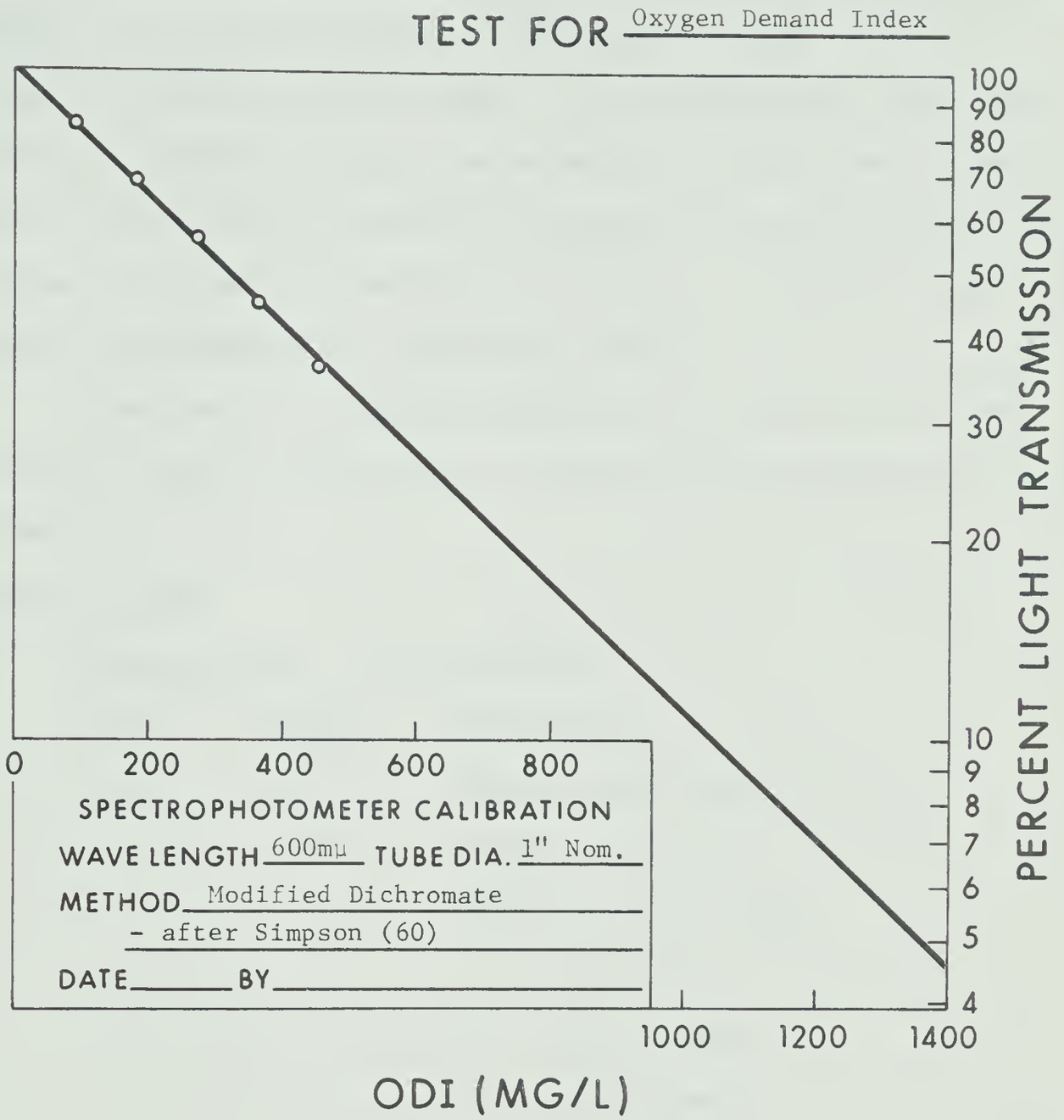
Procedure

1. Place 25 mm x 150 mm Nessler test tubes in rack.
   - The % transmission of tubes should vary not more than $\pm$ 1% among tubes.
   - One tube for blank + one per sample are required.

2. Add 0.1 g $HgSO_4$ powder to each tube (Note 2).
   - All $HgSO_4$ may not dissolve.
3. Add with pipet 5.0 ml distilled water to blank tube.
4. Add with pipet 5.0 ml of sample (or aliquot diluted to 5 ml) into each tube and swirl.
5. Add exactly with pipet 1.5 ml of 0.25N dichromate solution (Note 3).
6. Add carefully 7.5 ml of H_2SO_4 - Ag_2SO_4 solution (Note 4).
   - Caution: strong acid.
7. Mix well by swirling.
   - Caution: Tubes become very warm.
8. Place rack with blank and sample tubes in boiling water for 20 minutes (Note 5).
9. Remove and cool in water or let stand to cool (Note 6).
10. Read in Baush and Lamb "Spectronic 20" at 600 mμ, using the blank as 100% transmittance.
11. Calculate ODI value from graph by running a blank plus 1.0, 2.0, 3.0, 4.0 and 5.0 ml volumes of 600 mg/l glucose solution. These give % transmission readings for 0 (blank), 90, 180, 270, 360 and 450 mg/l ODI respectively (Note 7).

Notes:

1. The Ag_2SO_4 in the H_2SO_4 - Ag_2SO_4 reagent acts as a catalyst for the oxidation of straight-chain alcohols and acids that are present in the organic matter.
2. A slight excess of $HgSO_4$ is required to prevent interference from the chlorine ion. A large excess may increase settling time.
3. The quantity (1.5 ml) of chromate solution used is critical.
4. The amount of acid reagent is less critical but an excess or deficiency may affect the dilution and, therefore, the color concentration.
5. The temperature of boiling is not critical provided the blank is treated exactly as the samples. In some cases, room temperature may be sufficient to complete oxidation. Although he did not find the boiling point to be critical, Simpson (60) recommends that some primary work be done to find the best boiling period required for the type of waste being investigated. For beef cattle wastes, a boiling period of 20 minutes at 98°C was used.
6. The cooling period, usually a minimum of ten minutes, is required for the settling of insoluble salts. Errors in reading % transmittance may result if some salts are still suspended at time of reading. For beef cattle wastes, a 15 minute period was used.
7. With samples containing only biodegradeable material, the ODI values should be roughly equivalent to the BOD_5 values.


TEST FOR Oxygen Demand Index
100
90
80
70
60
50
40
30
20
10
9
8
7
6
5
4
PERCENT LIGHT TRANSMISSION
0
200
400
600
800
1000
1200
1400
ODI (MG/L)
SPECTROPHOTOMETER CALIBRATION
WAVE LENGTH 600mμ TUBE DIA. 1" Nom.
METHOD Modified Dichromate
- after Simpson (60)
DATE BY



APPENDIX VIII

FORTRAN PROGRAM FOR k AND L DETERMINATION

As previously stated in the text, the program uses three different methods for determining k and L. The "log-difference" (LD) and the "slope" (S) methods give the values in the program output while the "method of moments" (MM) gives the values for $\Sigma Y/\Sigma TY$, ΣY and ΣTY which are used in conjuction with the graphs developed by Moore et al (44). The program also permits the selection of either any one method or all three methods simultaneously for comparative purposes.

Actual data or a regression equation of the data may be used: that is, Y (mg/l) = B (log hours) + A where hours is the time from start of BOD test.

Format of Input

1. Parameter Card - 1 card required.

Column	Format	Information
1-3	I3	Number of data sets to be run.
6	I1	Methods to be used:
		ICODE = 0 - LD, S, MM
		1 - LD, S
		2 - LD, MM
		3 - S, MM
		4 - LD
		5 - S
		6 - MM.

2. Data Information Card - 1 card per data set.

Column	Format	Information
6-29	4A6	Sample identification (i.e.) date, year, location, etc.
30-38	F9.2	B - Regression coefficient; if not used, field is left blank.
39-47	F9.2	A - Regression intercept; if not used, field is blank.
49	I1	IDATA = 1 for actual data; 0 (blank) for regression.
50-51	I2	N = number of observations of actual data (including time 0 days) or for regression, number of observations wanted (excluding time 0 days, therefore, for 5-day BOD, N = 6).
52	I1	INFO3 = 1: if actual data time is in hours; (blank) 0: if actual data time is days or if regression is used.

3. Actual Data Cards - 1 card per observation. These cards must follow data information card and the number of cards must be equal to N. These are deleted if regression equation is used.

Column	Format	Information
1-9	F9.1	- BOD observation time (hrs. or days)
11-19	F9.1	- BOD (mg/l) at observation time.

Program Output

For each method, the name of the method used, the data identification, the regression equation (if used), and the time and BOD data used (actual or from regression equation) are given. The "slope" and "log-difference" methods give the growth rate or rate constant, k ($days^{-1}$), ultimate BOD, L (mg/l) and calculated BOD (Y) using k and L for a 10 day period where:

$$Y \text{ (mg/l)} = L\ (1 - 10^{-kt}).$$

The "slope" method also gives the probable errors of k and L, the lag correction factor (C) and the lag time (t_o) in days (and hours) where, from Thomas (70):

$$Y \text{ (mg/l)} = L\ (1 - 10^{-k(t-t_o)} = L\ (1 - C\ 10^{-kt}).$$

This method also gives the calculated BOD for a 10 day period using lag time.

The "method of moments" gives the sums as previously mentioned above to be used with the corresponding graphs given by Moore et al (44). The sequences given are for 1 to 3 days, 1 to 5 days and 1 to 7 days but the latter may not be given if $N < 8$.

```
C
C
C     PROGRAM TO DETERMINE ULTIMATE BOD(L) AND RATE CONSTANT (K) FOR THE
C     FIRST STAGE BOD CURVE.  THIS PROGRAM USES THREE METHODS:
C        (1) LOG DIFFERENCE METHOD - FAIR -1936,
C        (2) SLOPE METHOD - THOMAS - 1937 & 1940,
C        (3) METHOD OF MOMENTS - MOORE, THOMAS & SNOW - 1950.
C
C
      DIMENSION T(40),Y(40),H(40),DT(40),YBF(40),TLOGD(40),TENKT(40),
     1YP(40),EQBR(40),TSQ(40),TLH(40),YBM(40),YYBM(40),YSQ(40),YBC(40),
     2R(40),RSQ(40),TNKT(40),TNKTS(40),YTNKT(40),TY(40),D(40)
      DOUBLE PRECISION DATE,YEAR,INFO1,INFO2
      REAL NR,K,L,KT(40),LOGD(40)
      INTEGER X,V,Z
      READ (5,99) NO,ICODE
      NUM = 0
    1 READ (5,100) DATE,YEAR,INFO1,INFO2,B1,A1,IDATA,N,INFO3
      IF (IDATA.EQ.0) GO TO 4
      DO 3 X = 1,N
      READ (5,102) T(X),Y(X)
      IF (INFO3.EQ.0) GO TO 3
      T(X) = T(X)/24.
    3 CONTINUE
      GO TO 6
    4 CONTINUE
      H(1) = 0.
      T(1) = 0.
      Y(1) = 0.
      DO 5 X =2,N
      N3 =  X - 1
      H(X)  = H(N3)+24.
      T(X)  = H(X) /24.
      TL = ALOG10(H(X))
    5 Y(X)  = B1*TL+A1
    6 NUM = NUM + 1
      IF (ICODE.EQ.5) GO TO 17
      IF (ICODE.EQ.6) GO TO 27
      IF (ICODE.EQ.3) GO TO 17
C
C     LOG DIFFERENCE METHOD
C
      SUMYB = 0.
      SMTLD =0.
      SUMLD = 0.
      SUMY =0.
      SUMT = 0.
      SMTSQ = 0.
      DO 10 X = 2,N
      Z = X-1
      SUMY = SUMY + Y(X)
```

```
      SUMT = SUMT + T(X)
      TSQ(X) = T(X)**2
      SMTSQ = SMTSQ + TSQ(X)
      D(X) = Y(X) -Y(Z)
      DT(X) = T(X)-T(Z)
      IF (D(X).GT.0.) GO TO 9
      WRITE (6,183) NUM
      WRITE (6,150)
      WRITE (6,151)
      WRITE (6,150)
      WRITE (6,149) DATE,YEAR,INFO1,INFO2
      IF (IDATA.GT.0) GO TO 7
      WRITE (6,104) B1,A1
    7 WRITE (6,186) X,Z,D(X)
      WRITE (6,105)
      WRITE (6,155)
      DO 8  X = 1,N
    8 WRITE (6,185)  T(X),Y(X)
      GO TO 17
    9 LOGD(X) = ALOG10(D(X))
      SUMLD = SUMLD + LOGD(X)
      TLOGD(X) = T(X)*LOGD(X)
   10 SMTLD = SMTLD + TLOGD(X)
      N1 = N-1
      NR = FLOAT(N1)
      K = (SUMT*SUMLD-NR*SMTLD)/(NR*SMTSQ-(SUMT**2))
      DO 11 X = 2,N
      KT(X) = K*T(X)
      TENKT(X) = 10.**KT(X)
      EQBR(X) = 1. - (1./TENKT(X))
      YEBR(X) = Y(X)*EQBR(X)
   11 SUMYB = SUMYB + YEBR(X)
      L = (SUMYB)/(NR-((2.*(1./10.**K))*(1.-(1./10.**(NR*K)))/(1.-(1./10
     1.**K)))+ ((1./10.**(2.*K)) *(1.-(1./10.**(2.*NR*K))))/(1.-(1./10.**
     1(2.*K)))))
      DO 12 X = 2,N
   12 YP(X) = L*EQBR(X)
      WRITE (6,183) NUM
      WRITE (6,150)
      WRITE (6,151)
      WRITE (6,150)
      WRITE (6,149) DATE,YEAR,INFO1,INFO2
      IF (IDATA.GT.0) GO TO 13
      WRITE (6,104) B1,A1
      GO TO 14
   13 WRITE (6,152)
   14 WRITE (6,155)
      WRITE (6,185)  T(1),Y(1)
      DO 15 X = 2,N
   15 WRITE (6,153) T(X),Y(X),D(X),LOGD(X),TLOGD(X),KT(X),TENKT(X),
     1EQBR(X),YEBR(X),TSQ(X)
```

```
      WRITE (6,103)
      WRITE (6,154) SUMT,SUMLD,SMTLD,SUMYB,SMTSQ
      WRITE (6,156) K
      WRITE (6,157) L
      WRITE (6,158)
      DO 16 M = 1,10
      T1 = FLOAT(M)
      YC = L*(1.-(1./10.**(T1*K)))
   16 WRITE (6,159) M,YC
   17 CONTINUE
      IF (ICODE.EQ.4) GO TO 30
      IF (ICODE.EQ.2) GO TO 27
C
C     SLOPE METHOD
C
      SSUMY = 0.
      SYYPN = 0.
      SYSQ  = 0.
      SRSQ  = 0.
      STKT  = 0.
      STKTS = 0.
      SYTKT =0.
      SYPN =0.
      N1 = N-2
      NR = FLOAT(N1)
      I = N-1
      DO 18 X = 2,I
      Z = X-1
      V = X+1
      YPN(X) = ((Y(X)-Y(Z))*((T(V)-T(X))/(T(X)-T(Z)))+(Y(V)-Y(X))*((T(X)
     1-T(Z))/(T(V)-T(X))))/(T(V)-T(Z))
      SYPN = SYPN + YPN(X)
      YYPN(X) = Y(X)*YPN(X)
      YSQ(X) = Y(X)**2
      SYYPN = SYYPN + YYPN(X)
      SSUMY = SSUMY + Y(X)
   18 SYSQ = SYSQ + YSQ(X)
      B =((NR*SYYPN-SYPN*SSUMY)/(NR*SYSQ-SSUMY**2))*(-1.)
      K = .4343*B
      A = (SYSQ*SYPN - SYYPN*SSUMY)/(NR*SYSQ - SSUMY**2)
      L = A/B
C
C      LAG TIME FROM SLOPE METHOD
C
      RSQ(1) = 0.
      DO 19 X = 2,N
      Z = X-1
      SRSQ = SRSQ+RSQ(Z)
      YPC(X) = 2.30*K*(L-Y(X))
      R(X) = YPC(X) - YPN(X)
      RSQ(X) =R(X)**2
```

```
      KT(X) = K*T(X)
      TNKT(X) = 1./10.**(K*T(X))
      TNKTS(X) = TNKT(X)**2.
      YTNKT(X)= Y(X)*TNKT(X)
      STKT = STKT + TNKT(X)
      STKTS = STKTS + TNKTS(X)
   19 SYTKT = SYTKT + YTNKT(X)
      WRITE (6,193) NUM
      WRITE (6,162)
      WRITE (6,161)
      WRITE (6,162)
      WRITE (6,149) DATE,YEAR,INFO1,INFO2
      IF (IDATA.GT.0) GO TO 20
      WRITE (6,104) B1,A1
      GO TO 21
   20 WRITE (6,152)
   21 WRITE (6,171)
      WRITE (6,172) T(1),Y(1)
      DO 22 X = 2,I
   22 WRITE(6,169) T(X),Y(X),YPN(X),YYPN(X),YSQ(X),YPC(X),P(X),PSQ(X),
     1KT(X),TNKT(X),TNKTS(X),YTNKT(X)
      WRITE (6,199) T(N),Y(N),KT(N),TNKT(N),TNKTS(N),YTNKT(N)
      WRITE (6,173)
      WRITE (6,170) SSUMY,SYPN,SYYPN,SYSQ,SPSQ,STKT,STKTS,SYTKT
      WRITE (6,198)
      WRITE (6,156) K
      WRITE (6,157)  L
      EBRT = (NP/(NR*SYSQ-SSUMY**2))*(SPSQ/(NP-2.))
      EART = (SYSQ/(NR*SYSQ-SSUMY**2))*(SRSQ/(NR-2.))
      RTNEG = AMIN1(EBRT,EART)
      IF (RTNEG.LE.0.) GO TO 23
      EB = .674*(SQRT(EBRT))
      EA = .674*(SQRT(EART))
      EK = 0.4343*EB
      EL = SQRT((EA/B)**2+((A*EB)/B**2)**2)
      WRITE (6,163) EK,EL
   23 C  = (L*STKT-SYTKT)/(L*STKTS)
      IF (C.LE.0.) GO TO 24
      TLAG = (ALOG10(C))/K
      THP = TLAG*24.
      WRITE (6,165) C,TLAG,THP
   24 WRITE (6,158)
      WRITE (6,168)
      DO 25 M = 1,10
      T1 = FLOAT(M)
      YCS = L*(1.-1./10.**(T1*K))
      IF (C.LE.0.) GO TO 25
      YCSLT = L*(1.-1./10.**(K*(T1-TLAG)))
      WRITE (6,167) M,YCS,YCSLT
   25 CONTINUE
      IF (C.GT.0.) GO TO 27
```

```
      DO 26 M = 1,10
   26 WRITE (6,159) M,YRS
   27 CONTINUE
      IF (ICODE.EQ.5) GO TO 32
      IF (ICODE.EQ.1) GO TO 32
C
C     METHOD OF MOMENTS - MOORE,THOMAS AND SNOW - 1950
C
C     NOT VALID UNLESS T(1) = 0 & Y(1) = 0
C
C
      DO 28 X = 1,N
   28 TY(X) = T(X)*Y(X)
      SUMY1 = Y(2)+Y(3)+Y(4)+Y(1)
      SUMY2 = Y(2)+Y(3)+Y(4)+Y(5)+Y(6)+Y(1)
      SMTY1 = TY(2)+TY(3)+TY(4)+TY(1)
      SMTY2 = TY(2)+TY(3)+TY(4)+TY(5)+TY(6)+TY(1)
      WRITE (6,183) NUM
      WRITE (6,190)
      WRITE (6,191)
      WRITE (6,149) DATE,YEAR,INFO1,INFO2
      IF (IDATA.GT.0) GO TO 29
      WRITE (6,104) B1,A1
      GO TO 30
   29 WRITE (6,152)
   30 WRITE (6,106)
      DO 31 X = 1,N
   31 WRITE (6,107) T(X),Y(X),TY(X)
      WRITE (6,108)
      RATIO = SUMY1/SMTY1
      WRITE (6,192) SUMY1,SMTY1,RATIO
      RATIO = SUMY2/SMTY2
      WRITE (6,193) SUMY2,SMTY2,RATIO
      IF (N.LT.8) GO TO 32
      SUMY3 = Y(2)+Y(3)+Y(4)+Y(5)+Y(6)+Y(7)+Y(8)+Y(1)
      SMTY3 = TY(2)+TY(3)+TY(4)+TY(5)+TY(6)+TY(7)+TY(8)+TY(1)
      RATIO = SUMY3/SMTY3
      WRITE (6,194) SUMY3,SMTY3,RATIO
   32 CONTINUE
      IF (NUM.LT.NO) GO TO 1
      WRITE (6,98)
   98 FORMAT ('1',4X,'END OF DATA'//)
   99 FORMAT (I3,2X,I1)
  100 FORMAT (5X,4A6,2F9.2,1X,I1,I2,I1)
  102 FORMAT (F9.1,1X,F9.1)
  103 FORMAT (1X,'*****',22X,'**********',3X,'**********',20X, '*********',
     15X,'******')
  104 FORMAT (8X,'Y IS FROM REGRESSION:   Y(MG/L) = ',E7.0,'(LOG T) + ('
     1,E7.0,')  WHERE T = HRS FROM START OF TEST'//)
  105 FORMAT (1X,'IMPOSSIBLE TO TAKE LOG OF NEGATIVE NUMBER'//)
  106 FORMAT (5X,'T',10X,'Y',11X,'TY'/)
```

```
107 FORMAT (3X,F5.2,4X,F9.2,2X,E13.5)
108 FORMAT (4X,'******',4X,'**********',2X,'**************'///)
149 FORMAT ('0',7X,4A6//)
150 FORMAT (6X,'**********************************')
151 FORMAT (5X,'* LOG - DIFFERENCE METHOD *')
152 FORMAT (8X,'ACTUAL DATA USED'//)
153 FORMAT (1X,F5.2,1X,F9.2,1X,F9.2,2X,F9.5,2X,F9.3,1X,F9.3,1X,F9.3,1X
   1,F9.4,2X,F7.1,6X,F5.2)
154 FORMAT (1X,F5.2,21X,F9.4,3X,F9.3,30X,F9.1,5X,F5.2//)
155 FORMAT (3X,'T',9X,'Y',7X,'DIFF',4X,'LOG DIFF',4X,'T LOG D',6X,'KT'
   1,5X,'10**KT',3X,'1-10**KT',3X,'Y(COL 8)',5X,'T**2')
156 FORMAT (5X,'GROWTH RATE     K = ',F9.5/)
157 FORMAT (5X,'ULTIMATE BOD    L = ', F9.2,' PPM BOD'///)
158 FORMAT (5X,'CALCULATED BOD - DAY 1 TO DAY 10'/)
159 FORMAT (10X,'DAY ',I2,5X,F9.2,' MG/L ')
161 FORMAT (5X, '* SLOPE METHOD *')
162 FORMAT (6X,'*****************')
163 FORMAT (5X,'PROBABLE ERROR OF K = ',F9.6,5X,'PROBABLE ERROR OF L =
   1 ',F9.2)
165 FORMAT (5X,'LAG CORRECTION = ',F7.3,12X,'LAG TIME = 'F5.2,' DAYS
   1(',F5.2,' HRS)'/)
167 FORMAT (10X,I2, 5X,F8.1,' MG/L ',4X,F8.1,' MG/L')
168 FORMAT (8X,' TIME ',5X,'NO LAG ',3X,'USE LAG')
169 FORMAT (1X,F4.1,F9.2,1X,F9.2,1X,E12.5,1X,E12.5,1X,F9.2,1X,F9.4,1X,
   1F9.1,1X,F6.4,1X,F7.4,1X,F8.5,1X,F9.2)
170 FORMAT (4X,F9.1,1X,F9.1,1X,E12.4,1X,E12.4,22X,F9.1,8X,F7.4,1X,F9.5
   1,1X,F5.2)
171 FORMAT (3X,'T',7X,'Y',8X,'YP',8X,'Y**YP',9X,'Y**2',7X,'YPCALC',5X,
   1'R',7X,'R**2',5X,'KT',3X,'10**-KT',1X,'10**-2KT',1X,'Y*10**-KT')
172 FORMAT(1X,F4.1,    F9.2,'*')
173 FORMAT (5X,'*********',1X,'**********',1X,'**************',1X,'******
   1******',21X,'********',8X,'********',1X,'*********',1X,'**********')
183 FORMAT ('1',1X,'NUMBER ',I3//)
185 FORMAT (1X,F5.2,1X,F9.2)
186 FORMAT (5X,'T(',I2,')-T(',I2,') = ',F9.2/)
190 FORMAT      (2X,'METHOD OF MOMENTS - MOORE,THOMAS AND SNOW - 1950')
191 FORMAT (3X,'**********************'///)
192 FORMAT (5X,'FOR 1-3 DAY SEQUENCE:  SUM OF Y = ',F9.0,'; SUM OF TY
   1= ',F9.0,'; SUM Y/SUM TY = ',F8.6//)
193 FORMAT (5X,'FOR 1-5 DAY SEQUENCE:  SUM OF Y = ',F9.0,'; SUM OF TY
   1= ',F9.0,'; SUM Y/SUM TY = ',F8.6//)
194 FORMAT (5X,'FOR 1-7 DAY SEQUENCE:  SUM OF Y = ',F9.0,'; SUM OF TY
   1= ',F9.0,'; SUM Y/SUM TY = ',F8.6//)
198 FORMAT (5X,'* NOT INCLUDED IN SUM'//)
199 FORMAT (1X,F4.1,    F9.2,'*',66X,F6.4,1X,F7.4,1X,F8.5,1X,F9.2)
    STOP
    END
```

APPENDIX IX

QUANTITIES OF WASTE CHARACTERISTICS, WASTE NUTRIENTS AND FEED NUTRIENTS

The data presented in the following tables are the cumulative quantities of:

(a) liquid waste characteristics (lb./pit);

(b) plant nutrients (lb./pit); and

(c) livestock feed nutrients (lb./pit).

Sections A and B were determined using the variable concentrations and the pit volumes and are the quantities present in each pit.

Section C was determined using the livestock feed records and feed analyses and are the quantities fed to the animals contributing wastes to the individual pits. Since the animals in Pens B and C were contributing wastes to both aerobic pits, the average quantities of feed nutrients for these pens were used for Pits No. 1 and No. 2. Similarly, the average quantities for Pens A and D were used for the anaerobic pits, No. 3 and No. 4.

SECTION A: LIQUID WASTE CHARACTERISTICS (LB./PIT).

	Test Day	BOD_{5T} lb.	ODI lb.	TS lb.	VTS lb.
Pit 1	79	148	-	-	-
	86	123	-	3157	2444
	94	238	-	-	-
	100	229	-	4147	3110
	107	299	430	4663	3497
	114	231	554	5055	3684
	121	319	616	5320	3706
	127	270	705	5709	4095
	133	229	515	5458	3851
	142	388	509	6314	4608
	149	389	926	6097	4424
	156	496	819	6217	4334
	163	394	789	6047	4147
	170	412	897	6426	4693
	177	531	897	6456	4424
	184	534	1084	6425	4385
	191	546	1303	6303	4446
	197	485	1100	6217	4155
	203	432	1214	6247	4125
	209	-	1279	6163	4233
Pit 2	79	162	-	-	-
	86	299	-	3562	2844
	94	292	-	-	-
	100	327	-	4492	3312
	107	317	430	5111	3766
	114	211	676	5440	3975
	121	439	726	5616	4060
	127	316	766	6019	4348
	133	364	707	5768	4014
	142	404	643	6116	4216
	149	416	937	5856	4124
	156	485	723	6034	4201
	163	462	952	6167	4360
	170	409	787	6455	4682
	177	499	1079	6433	4519
	184	611	1063	6964	4891
	191	474	1212	7103	5219
	197	493	1170	6327	4280
	203	646	1119	6344	4267
	209	-	1176	6059	4099

Cont'd.

	Test Day	BOD_{5T} lb.	ODI lb.	TS lb.	VTS lb.
Pit 3	79	403	-	-	-
	86	747	-	2541	2062
	94	828	-	-	-
	100	992	-	3722	2760
	107	893	347	4242	3310
	114	977	485	3157	2359
	121	1043	604	3638	2711
	127	1184	624	4430	3296
	133	1267	770	6193	4464
	142	1514	798	6477	4368
	149	1449	1038	6006	4495
	156	1515	1013	6380	4585
	163	1181	1041	6396	4632
	170	1636	880	6312	4610
	177	1953	1094	7239	5303
	184	1883	1313	6995	4966
	191	2021	1753	6304	4707
	197	1894	1380	7197	5135
	203	1968	1345	6810	4942
	209	-	1345	6852	4900
Pit 4	79	499	-	-	-
	86	735	-	2272	1793
	94	755	-	-	-
	100	794	-	2636	2016
	107	945	373	3824	2956
	114	1063	545	3422	2525
	121	947	522	3432	2437
	127	1056	638	4395	3190
	133	1163	644	5339	4059
	142	1356	783	7306	5310
	149	1531	949	4665	3389
	156	1591	1025	5002	3731
	163	1362	1022	5689	4319
	170	1675	1035	6355	4756
	177	1865	984	6311	3939
	184	1781	1311	7576	5538
	191	1878	1710	6247	4696
	197	1753	1434	6261	4577
	203	1548	1364	5570	4016
	209	-	1397	6355	4714

SECTION B: PLANT NUTRIENTS (LB/PIT).

	Test Day	DM lb	P lb	K lb	N_T lb	N_O lb	N_{NH_3} lb
Pit 1	103	4892	47.7	127	135	127	8.4
	110	4734	48.0	128	157	123	35.6
	117	5024	55.8	135	170	135	34.7
	131	5447	56.8	146	179	140	38.5
	138	5117	59.9	144	182	140	42.5
	152	5793	77.6	149	235	166	69.6
	166	6344	89.4	170	257	194	62.8
	180	6735	88.4	206	293	188	104.4
	194	6589	90.4	184	261	171	89.7
	205	6264	93.4	180	248	206	42.5
Pit 2	103	4846	48.5	140	170	145	25.7
	110	5106	52.3	153	192	151	41.2
	117	5287	55.9	157	202	151	51.6
	131	5878	61.6	163	206	173	33.3
	138	5659	63.1	171	217	168	48.5
	152	5857	75.8	158	244	175	68.5
	166	6510	89.0	192	249	204	45.1
	180	7491	98.8	212	258	223	34.7
	194	6410	87.8	187	250	196	54.4
	205	6290	96.5	192	248	219	28.7

	Test Day	DM lb	P lb	K lb	N_T lb	N_O lb	N_{NH_3} lb
Pit 3	103	3736	30.9	113	193	105	88
	110	3227	29.0	124	196	110	86
	117	3999	36.6	137	228	125	104
	131	5004	42.1	152	244	145	99
	138	5354	45.4	163	248	164	84
	152	4335	50.6	120	340	148	192
	166	7145	75.6	183	371	207	164
	180	7274	69.3	184	360	185	175
	194	6627	73.2	202	385	207	179
	205	6822	77.6	182	395	214	180
Pit 4	103	3774	32.0	87	241	102	139
	110	3120	28.5	125	192	96	97
	117	3610	35.4	127	212	106	106
	131	4243	44.6	142	220	134	86
	138	3826	38.3	140	227	134	94
	152	4949	56.1	159	296	157	139
	166	7171	82.0	179	365	218	147
	180	7260	72.6	190	320	208	112
	194	6181	66.3	194	372	184	187
	205	6114	64.6	157	385	188	197

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